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Final Technical Report

Ruptures and Spills

Prepared for
Bureau of Land Management
July 1981

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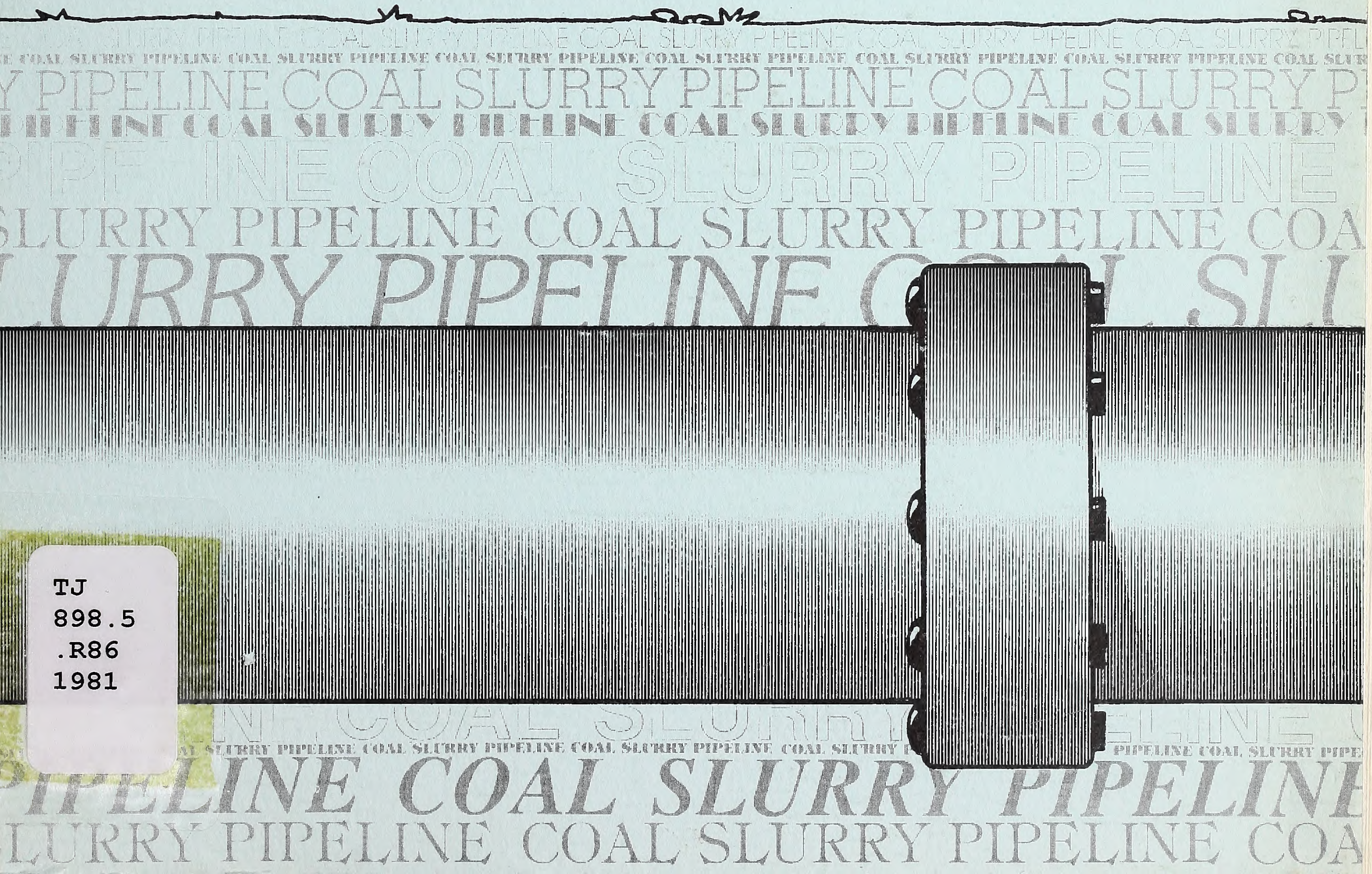
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FINAL
RUPTURES AND SPILLS
TECHNICAL REPORT
for the
ETSI Coal Slurry Pipeline Project

July 1981

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Prepared by Woodward-Clyde Consultants for
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Contents

Chapter 1: SPILL ACCIDENT ANALYSIS

Page
1.A Introduction 1
1.B Sources and Causes 1
1.C Historical Spills 3
1.D Predicted Spill Frequency 4
1.E Predicted Spill Magnitudes 5
1.F Chronic Spills 8

Chapter 2: SLURRY CHARACTERISTICS

2.A Physical Characteristics 12
2.B Chemical Characteristics 12

Chapter 3: SPILL MOVEMENT AND FATE

3.A Receiving Water Impacts 25
    3.A.1 Streams and Rivers 25
    3.A.2 Lakes and Reservoirs 28
3.B Ground Water Impacts 29
3.C Terrestrial Impacts 31
3.D Pipeline Flow 32

Chapter 4: IMPACT ASSESSMENT

4.A Approach 33
4.B Spill Scenarios 35
    4.B.1 Scenario Descriptions 35
    4.B.2 Scenario Spill Modeling 35
    4.B.3 Water Quality Impacts 83
    4.B.4 Ecological Impacts 109
    4.B.5 Other Impacts 130
4.C Unavoidable Impacts 131

REFERENCES 133
APPENDIX: POTENTIAL PIPELINE SPILLS 141

Chapter 1
SPILL ACCIDENT ANALYSIS

1.A INTRODUCTION

Parameters needed to evaluate the possible impacts of accidental pipeline discharges to the environment include pipeline spill frequencies, spill volumes and rates of discharge. This section discusses sources and causes, historical spills, and predicted spill frequencies and volumes.

No accident statistics are available for coal slurry pipeline spills as there have been only two operating pipelines in the United States and, due to their low hazard nature, spill reports are not required by the U.S. Department of Transportation Office of Pipeline Safety Operations (OPSO). Consequently, the coal slurry pipeline spill analysis must be derived from statistics involving interstate hazardous liquid pipelines.

1.B SOURCES AND CAUSES

From 1968 to 1976 (1976 being the latest year for which official statistics were published), the number of liquid pipeline accidents has decreased markedly. The trends in the categories of line pipe accidents can be seen in Table 1-1. More important than the total number of accidents for each cause is the percent of the total, which is independent of the fluctuating number of pipeline miles in operation.

Equipment rupturing the pipeline has replaced corrosion as the major cause of pipeline accidents. Corrosion-induced spills have steadily decreased since 1969, probably as a result of federal regulations requiring that cathodic protection systems be installed on all coated pipelines by March 31, 1973.

Since the ETSI pipeline will be coated and cathodically protected, it would be most accurate to utilize accident data for similarly protected pipelines.

TABLE 1-1

LIQUIDS PIPELINES - YEARLY ACCIDENT SUMMARY (ALL ACCIDENTS), 1968-1976

Cause	Number of Accidents									Percentage of Total								
	1968	1969	1970	1971	1972	1973	1974	1975	1976	1968	1969	1970	1971	1972	1973	1974	1975	1976
Corrosion	232	172	179	124	100	86	67	72	51	46.5	42.7	51.5	40.2	32.5	31.7	26.2	28.3	24.4
Equipment Rupturing line	98	90	70	67	69	66	78	73	67	19.7	22.4	20.2	21.8	22.3	24.2	30.5	28.6	32.0
Defective Pipe	36	35	32	31	32	21	20	15	14	7.2	8.7	9.2	10.1	10.4	7.6	7.8	5.9	6.7
Defective Welds	4	3	3	3	5	5	4	5	4	.8	.7	.9	1.0	1.6	1.7	1.6	2.0	1.9
Incorrect Operations	14	13	13	22	22	16	28	22	20	2.8	3.2	3.8	7.1	7.1	6.0	10.8	8.6	9.6
Other	115	90	50	61	81	79	59	68	53	23	22.3	14.4	19.8	26.1	28.8	23.1	26.6	25.4
Total:	499	403	347	308	309	273	256	255	209									

Source: U.S. Department of Transportation, Office of Pipeline Safety Operations.

Note: Yearly accident numbers include all pipeline facilities, including line pipe.

However, since data pertaining to total miles of corrosion-protected versus non-protected pipelines are not available from the OPSO, the accident analysis must consider all pipeline types.

The problems associated with the quality of new pipe and its installation, as shown in the above data, are small in number relative to other categories.

The percentage of the total accidents caused by incorrect operation by pipeline carrier personnel has steadily increased since 1968, as have accidents due to vandalism, weather, and equipment failure, all of which are included under the "other" causes category.

1.C HISTORICAL SPILLS

To date only two coal slurry pipelines have ever been constructed within the United States; the Black Mesa Pipeline in Arizona and the Consolidation Pipeline in Ohio. The latter was taken out of operation shortly after construction with no reported spill history. The only available spill data concern an incident involving the Black Mesa Coal Slurry Pipeline.

On February 18, 1977, a total of 11,000 barrels of slurry containing approximately 1200 tons of coal spilled from two ruptures in the Black Mesa Pipeline. The breaks occurred when a worker in the Mojave Coal Electric Plant at Bull Head City failed to open a pressure relief valve during slurry transport, causing the 18-inch line to rupture at two locations. One rupture was located just west of Kingman in the Sacramento Valley and the other east of Kingman and southwest of the Peacock Mountains. To further compound the problem, the aforementioned worker failed to believe the pipeline monitoring equipment indicating a line break, thus delaying shutdown and allowing a larger spillage than necessary.

At both spill sites the discharged slurry flowed down narrow, dry washes adjoining the pipeline until the slurry water was exhausted from ground infiltration. The slurry traveled approximately six miles down the wash at the

Sacramento Valley site whereas it extended only three miles at the other site. Thickness of the hardened slurry in the washes varied from 4 inches near the spill source to 1 inch or less a few miles downstream. Hydraulic erosion in the washes was evident for approximately the first 100 yards. Trees in the immediate area were covered with slurry, and forbs and grasses were buried.

Due to the inert nature of the coal, representatives from the U.S. Bureau of Land Management and Arizona Game and Fish Department determined that any action taken toward removal or accelerated dispersion would result in greater environmental damage than a no-action alternative. Therefore, the spilled slurry was left to undergo natural dispersion. It had been suggested that spill-induced erosion through native plant loss could be checked by reseeding. However, reseeding was not undertaken. Had heavy equipment been used to remove the coal or aid natural dispersion, unnecessary damage could have occurred in the form of long-term tractor and road scars, physical damage to native vegetation and natural drainages, and increased soil erosion.

Within a number of days following the spill, most of the finer coal particles were carried away by the wind with the remaining material becoming somewhat compacted. Subsequent wind and precipitation transported up to one inch of this compacted coal to the sides of the wash where it was mixed with the existing sand and gravel materials. The presence of precipitation assisted in breaking the coal into smaller particles, allowing for easier transport by wind and water. Trampling by livestock further aided in the breakup of the coal. Some coal was removed by the public as they thought it a possible fuel source. As a result of the above factors, approximately 80 percent of the coal had been naturally dispersed or carried away after five months with only scattered pockets of coal less than 1 inch thick remaining.

1.D PREDICTED SPILL FREQUENCY

Accurate spill frequency predictions are difficult to assess for new installations due to the nature of the available data base. As discussed previously, the data base includes all operating liquid pipelines regardless of age or construction methods used, if any, to minimize spills. Therefore, those spill frequency predictions made in this report should be considered to be somewhat conservative.

Simple calculations of spill frequencies in the form of total accidents expected per mile of pipeline per year can be made by dividing the number of accidents in a given year with the number of existing pipeline miles in operation. Utilization of several years of data will give a more representative number of spills. Table 1-2 lists the spill frequencies for all liquid pipelines for the years 1968-1975. From this analysis it can be seen that the spill frequency rate has decreased by over 50 percent during this period even though the total mileage of pipeline in operation has increased slightly. This can be attributed to older pipelines being taken out of service and the increasing use of cathodic protection systems and coated pipe to inhibit corrosion, one of the leading causes of pipeline leaks.

When the annual accident-per-mile data versus the yearly data from Table 1-2 are fitted to a power law equation, the trend in accidents per mile is easily seen. This trend would indicate that annual rates on the order of 0.001 accidents per mile of pipeline will be the norm for the mid-1980s. Because the ETSI pipeline will be new, it is expected that it will not have any greater yearly accident rate than the predicted national annual rate of 0.001 per mile. Therefore, using the national average for all pipelines and approximately 1800 miles of pipeline in the ETSI case, the average leak frequency would be on the order of two leaks per year for the system. In interpreting this number, one must keep in mind that the ETSI system will be new and will be utilizing state-of-the-art technology and should be in a position to operate at less than this frequency.

1.E PREDICTED SPILL MAGNITUDES

Spill magnitude predictions involving the ETSI coal slurry pipeline are based primarily on the mean pipe diameter of the system with throughput, being a strong function of pipe diameter, being a secondary consideration. Because

TABLE 1-2

REPORTED LINE PIPE ACCIDENTS ALL CAUSES - ALL PRODUCTS

Year	Reported Number of Accidents[a]	Reported Number of Trunk Pipeline Miles	Accidents Per Mile
1968	421	115,238	.0037
1969	350	117,983	.0030
1970	288	122,365	.0024
1971	258	122,471	.0021
1972	235	124,458	.0019
1973	194	122,354	.0016
1974	199	126,211	.0016
1975	180	121,278	.0015
1976	169	b	b

Source: National Transportation Safety Board 1978.

[a] Note that these figures are for line pipe only and do not include pump station or related facilities accidents.

[b] Data not yet available from ICC Part 6 Report.

pipe diameter decreases after each delivery point, spills occurring along the southernmost sections of the pipeline will likely be of lesser magnitude than the mainline.

In addition, these magnitudes are based on a formula developed for liquid pipelines and may differ somewhat for coal slurry lines due to the physical properties of the slurry. For small holes less than 0.250 inch in diameter, the coal particles usually plug the hole immediately and may remain so indefinitely whereas larger holes will, in most cases, become enlarged by the abrasive action of the leaking slurry. Neither of these processes occurs in liquid pipelines.

Beyer and Painter (1977) have developed methodology for relating pipeline diameter to mean spill size. The curve fitted data for mean spill size is given by the following equation:

$$\overline{S} = 2.06D^{2.27}$$

Where $\overline{S}$ = mean spill size (bbl)

D = pipe outside diameter (inches)

For the proposed ETSI system, where 1733 miles of various pipeline diameters are involved, the following equation can be used to estimate the weighted mean spill size:

$$\overline{S}_T = \sum_{n=1}^{9} L_n \overline{S}_n = 8,241 \text{ bbl}$$

Where $\overline{S}_T$ = weighted mean system spill size (bbl)

L_n = percent of total pipeline length assigned to an individual diameter

$\overline{S}_n$ = spill size predicted for a given diameter n (bbl)

The following data summarizes the proposed ETSI configuration:

D	Length (miles)	L_n	S_n
46.00	807.5	46.596	12,255
40.00	189.9	10.958	8,924
36.00	80.2	4.628	7,025
32.00	291.4	16.815	5,377
26.00	75.6	4.362	3,356
24.00	16.0	0.923	2,799
16.00	159.0	9.175	1,115
14.00	89.0	5.136	823
10.75	24.0	1.385	452

If the above data is utilized, a mean system spill size of 8,241 barrels is predicted. This mean system spill size can be related to the spill frequency number generated.

For comparison purposes, Table 1-3 has been included to give a simple analysis of historical spill data. As can be seen, no obvious trends exist with regard to quantity spilled. The average loss per accident has shown an increase but lacks an orderly progression making it difficult to consider it a trend.

1.F CHRONIC SPILLS

For purposes of this analysis, chronic spills are defined as those spills below the instrument detection limit which contaminate localized areas continually without being visually detected. The pipeline instrument detection level is assumed to be 1.5 percent of the pipeline flow rate, or a maximum of 562.5 barrels per hour along the initial, high volume sections of the pipeline. Review of actual or simulated coal slurry pipeline leaks indicates that for holes less than 0.250 inch in diameter, coal particles immediately plug the hole and leakage stops until a water batch pases when the hole may leak water. If a leak has not been detected by the time slurry returns to the line, the leak may stop again. This cycle could continue indefinitely unless the hole is either discovered or grows larger. Leaking slurry would in most cases enlarge the hole after a period of time. Although coal is not extremely abrasive, there are data showing that at high velocities carbon steel is removed with time. Small leaks of this nature can be caused by any of several things, including but not limited to corrosion, excavation, excavation equipment, farm plows, and defective pipe.

TABLE 1-3

LIQUIDS PIPELINES - NUMBER OF ACCIDENTS VERSUS QUANTITY SPILLED

Year	Number of Accidents[a]	Commodity Loss in Barrels	Average Loss Per Accident
1968	499	392,588	787
1969	403	343,691	853
1970	347	521,849	1504
1971	308	245,057	796
1972	309	360,654	1167
1973	273	379,365	1390
1974	256	293,643	1147
1975	255	319,423	1253
1976	209	255,037	1220

Source: U.S. Department of Transportation, Office of Pipeline Safety Operations

[a] Yearly accident numbers include all pipeline facilities, including line pipe.

Table 1-4 is a leak detection matrix that shows the hole size that could develop before detection by the slurry metering systems, given different pipeline flows and internal pressures. ETSI would measure differences in flows between pump stations to an accuracy of 1.5 percent of the flow rate. Given this 1.5 percent criterion, the hole size (diameter) at detection is estimated to be less than 1 inch. These numbers were developed using a range of possible steel wear rates and velocities through the hole in the pipe. In all cases the hole was modeled as a round orifice type. If one assumes that a 0.250-inch hole is the size at which slurry begins to leak, then high and low wear rate scenarios, combined with different internal line pressures and flows, are used to estimate possible undetected spill sizes. The range of times to detection as well as maximum losses are tabulated. This calculation shows that a leak, where the line pressure is above 500 psig, will be detected by flow measurements before it is 1 inch in diameter.

Holes smaller than the detection threshold size must be detected by aerial or ground patrol, or third parties. The large estimated maximum material loss before detection by differential station flows illustrates the small probability that a small leak would go undetected by patrols or third parties for a long period of time.

TABLE 1-4

LEAK DETECTION MATRIX[a] – POSSIBLE SCENARIO FOR 0.250-INCH LEAK SIZE

P/L Flows (gpm)	Pressure (psig)	Initial Hole Size (in.)	Hole Size At Detection (in.)	Time Range (hrs)[b]		Est. Max. Material Loss Before Instr. Detection (bbl)	
				High Wear	Low Wear	High Wear	Low Wear
25,000	1500	0.250	0.595	63	342	34,000	183,000
20,000	1500	0.250	0.532	51	280	22,000	120,000
15,000	1500	0.250	0.461	38	209	12,000	67,000
10,000	1500	0.250	0.376	23	125	5,000	27,000
5,000	1500	0.250	0.266	2	16	300	1,700
25,000	1000	0.250	0.658	116	575	62,000	308,000
20,000	1000	0.250	0.589	96	477	41,000	204,000
15,000	1000	0.250	0.510	74	366	24,000	118,000
10,000	1000	0.250	0.416	47	234	10,000	50,000
5,000	1000	0.250	0.294	13	62	1,000	7,000
25,000	500	0.250	0.783	323	1361	173,000	729,000
20,000	500	0.250	0.700	273	1150	117,000	493,000
15,000	500	0.250	0.606	216	910	70,000	293,000
10,000	500	0.250	0.495	149	626	32,000	134,000
5,000	500	0.250	0.350	61	256	7,000	27,000

[a] Based on leak detection at 1.5% of pipeline flows.

[b] Based on high and low range of steel wear rates.

Chapter 2

SLURRY CHARACTERISTICS

2.A PHYSICAL CHARACTERISTICS

The proposed ETSI Coal Slurry Pipeline includes three preparation plants at which coal would be crushed and mixed with water, to form a slurry composed of 40 percent solids and 60 percent water, by weight. The size classification, specific gravity, and other physical characteristics of the slurry are presented in Table 2-1.

TABLE 2-1

PHYSICAL CHARACTERISTICS OF THE PROPOSED COAL SLURRY

Composition by Weight:	40 Percent Solids 60 Percent Water
Specific Gravity (Coal)	
Bone Dry:	1.45
Saturated:	1.298
Slurry Density:	1.142
Saturated Volume Concentration (Solids):	0.476
Size Classification (by weight):	14 Tyler Mesh, 0% Percent Retained 20 Tyler Mesh, 1% Percent Retained 325 Tyler Mesh, 77% Percent Retained

Source: BLM 1980.

2.B CHEMICAL CHARACTERISTICS

The chemical characteristics of the slurry would depend upon a number of factors, principally the characteristics of the source coal and source water, and the degree of processing during slurry preparation. As shown by Moore (1977) and

Manahan and Godwin (1979), equilibrium conditions in the pipeline may be established within the first 24 hours of anaerobic travel time. Thus, detention or travel time in the pipeline may be a negligible factor.

A number of investigators have performed chemical analyses on coal slurry mixtures under actual pipeline transport and simulated laboratory conditions (Science Applications Inc. 1977; Peavy et al. 1979; Keogh 1978; Moore 1979; Manahan and Godwin 1979; and UCLA/SAI 1978). (Chapter 1 of the Surface Water Quality Technical Report [WCC 1981a] contains a complete description of these investigations.) The results of these studies indicate that coal slurry mixtures may exhibit a wide variability in terms of the leaching of organic and inorganic constituents from coal into carrier water due to different combinations of source coal and source carrier waters. Given the variability shown, laboratory simulation with the proposed coal and carrier water was necessary in order to adequately define the chemical characteristics of potential slurry spills. Such simulated coal slurry transport studies have been performed, using project-specific coal and water sources. Coal samples taken from the Jacobs Ranch and Black Thunder mines have been crushed to project design classifications (Table 2-1) mixed with water samples from both the Madison Aquifer and Oahe Reservoir, and mixed (rolled) over a fifteen day period to simulate maximum pipeline transport time. Following vacuum filtration, the filtrate has been analyzed for a number of chemical and biochemical parameters. A complete description of these investigations can be found in the Surface Water Quality Technical Report (WCC 1981a) and in Plummer and Associates (1980a, 1980b, 1981).

Results available to date are shown in Tables 2-2 to 2-5.

Chemical analyses (PJB Laboratories 1980) for the 129 priority pollutants specified by the U.S. EPA have been performed on the filtrate resulting from two separate simulation runs. These included the simulated transport and dewatering of a Jacobs Ranch coal sample with a Madison Aquifer groundwater sample and a Jacobs Ranch coal sample with an Oahe Reservoir surface water sample.

With the exception of methylene chloride, which is likely due to unavoidable sampling contamination, and bis(2-ethyl-hexyl phthalate), which may also be due to

TABLE 2-2

TABULATION OF COAL SAMPLES AND WATER SAMPLES TESTED IN VARIOUS SIMULATION RUNS

Simulation Run	Source of Water	Water Sample	Source of Coal	Coal Sample	Age of Coal Sample
1	ETSI well M-1	422	Black Thunder	456-1	Fresh
2	ETSI well M-1	422	Kerr-McGee	456-2	Fresh
3	ETSI well M-14	470	Kerr-McGee	467	Fresh
4	Oahe Reservoir	473-1	Kerr-McGee	467	Fresh
5a	ETSI well M-14	470	Kerr-McGee	467	3 mos
5b	ETSI well M-14	470	Kerr-McGee	467	3 mos
6a	Distilled water	--	Black Thunder	490	Fresh
6b	Upton 4	489-1	Black Thunder	490	Fresh
6c	Devils 4	489-2	Black Thunder	490	Fresh
7a	Upton 4	489-1	Black Thunder	490	2 mos
7b	Upton 4	489-2	Black Thunder	490	2 mos

Source: Plummer 1981.

TABLE 2-3

SUMMARY OF SLURRY LEACH TEST RESULTS

			Water Source			Leach Results - Final Analysis													
Test No.	Coal Sample	Sample I.D.	TDS[1]	TC/TA[2]	Cond.[3]	TOC[4]	COD[4]	BOD (Filt.)[5]	TDS mg/l	TDS %Incr.	TC/TA mg/l	TC/TA %Incr.	Cond. (mmhos)	TOC[4]	COD[4]	No. of Days	BOD[4] Unfilt.	BOD[4] Filt.	BOD[4] 5,6
1.	Black Thunder Mine	ETSI #422	470	385	715	5	5	--	867	84%	614	59%	1160	31	109		--	--	--
2.	Kerr-McGee Jacobs Ranch Mine	ETSI #422	470	385	715	5	5	--	1337	184%	976	154%	1650	37	92		--	--	--
3.	Kerr-McGee Jacobs Ranch #467	ETSI #470 (Niobrara) Well M-14	471	402	657	5	6.3	--	916	94%	664	65%	1130	71	180	(5) (20) (30)	134 173 284	124 147 248	110 136 143
4.	Kerr-McGee Jacobs Ranch #467	ETSI #473-1 (Oahe)	544	431	793	8	19	--	903	66%	670	55%	1240	50	137	(5) (20) (30)	-- -- --	80 100 110	-- -- --
5a.	Kerr-McGee Jacobs Ranch #467	ETSI #470 (Unheated)	433	390	682	4	6	(5) 11 (20) 14 (30) 17	1406	225%	965	147%	1650	96	205	(5) (20) (30)	-- -- --	140 175 197	-- -- --
5b.	Kerr-McGee Jacobs Ranch #467	ETSI #470 (Heated)	415	390	642	5	9	(5) 9 (20) 17 (30) 18	1520	266%	994	155%	1690	129	275	(5) (20) (30)	-- -- --	165 216 240	-- -- --
6a.	Black Thunder	ETSI #490	Distilled Water			--	--	--	416	--	258	--	555	41	84	(5)	--	45	--
6b.	Black Thunder	#490	476	(#489-1) 392	654	11	5	(5) 4	602	26%	424	8%	862	41	79	(5)	--	43	--
6c.	Black Thunder	#490	549	(#489-2) 444	677	16	5	(5) 2	625	14%	448	1%	884	37	73	(5)	--	37	--
7a.	Black Thunder	#490	476	392	654	11	5	(5) 4	988	107%	682	74%	1300	25	50	(5) (20) (30)	-- -- --	19 31 38	-- -- --
7b.	Black Thunder	#490	476	392	654	11	5	(5) 4	695	46%	479	22%	934	40	61	(5) (20) (30)	-- -- --	52 71 89	-- -- --

Source: Plummer 1981.

[1] TDS = total dissolved solids (mg/l)

[2] TC/TA = total cations or total anions (mg/l as $CaCO_3$)

[3] Cond. = electrical conductivity (mmhos/cm)

[4] Milligrams per liter

[5] Test performed on filtered samples

[6] Test performed with nitrogenous demand suppressed

TABLE 2-4

SUMMARY OF FILTRATE TEST RESULTS

Test Number	1	2	3	4	5a	5b	6b	6c	7a	7b
Cations (mg/l as $CaCO_3$)										
Sodium	181	156	113	152	109	118	300	313	392	335
Potassium	14	25	16	18	18	24	9	10	10	9
Calcium	267	499	337	320	509	564	70	80	169	85
Magnesium	152	296	198	181	329	288	45	45	111	50
TOTAL	614	976	664	671	965	994	424	448	682	479
Anions (mg/l as $CaCO_3$)										
Nitrates	0	0	0	1	0	1	1	0	0	0
Chloride	45	45	8	15	4	2	5	3	3	4
Sulfates	482	736	404	479	795	783	246	294	626	310
Bicarbonates	87	195	252	176	166	208	172	151	53	140
TOTAL	614	976	664	671	965	994	424	448	682	479
TDS (mg/l)	867	1337	916	903	1406	1520	602	625	988	695
pH 7.8	7.8	8.0	7.8	6.6	6.0	7.9	7.7	7.4	7.8	
TOC (mg/l)	31	37	71	50	96	129	41	37	25	40
BOD_5 (mg/l)	N/A	N/A	134	80	140	165	43	37	19	52
COD (mg/l)	109	92	180	137	205	275	79	73	50	61
Significant Metals										
Copper ($\mu g/l$)	9.9	3	21	55	21	91	3	14	N/A	N/A
Nickel ($\mu g/l$)	1	110	25	19	8	8	11	2		
Zinc ($\mu g/l$)	1	160	20	50	38	53	30	9		
Manganese ($\mu g/l$)	2	28	230	3	140	210	4	4		
Iron ($\mu g/l$)	2	2	5	10	3	4	200	300		
Coal	Black Thunder	Kerr-McGee	Kerr-McGee	Kerr-McGee	Kerr-McGee	Kerr-McGee	Black Thunder	Black Thunder	Black Thunder	Black Thunder
Comments:	Fresh sample	Fresh sample	Fresh sample	Fresh sample	Same as 3 & 4 3 mos later		Fresh sample	Fresh sample	2 mos old (old grind)	2 mos old (new grind)

Source: Plummer 1981.

N/A = not tested.

TABLE 2-5

RANGE OF CONCENTRATIONS IN ETSI SIMULATION TEST SLURRY FILTRATES

Parameter	Range of Values[a] Measured
Cations (mg/l as $CaCO_3$)	
Sodium	100 - 390
Potassium	10 - 25
Calcium	70 - 570
Magnesium	45 - 330
TOTAL	425 - 1000
Anions (mg/l as $CaCO_3$)	
Chloride	2 - 45
Sulfate	250 - 800
Bicarbonate	90 - 250
TOTAL	425 - 1000
TDS (mg/l)	600 - 1500
pH	6.0 - 8.0
TOC (mg/l)	25 - 129
BOD_5 (mg/l)	19 - 165
COD (mg/l)	50 - 275
Significant Metals	
Copper (μg/l)	< 3 - 91
Nickel (μg/l)	< 1 - 110
Zinc (μg/l)	< 1 - 160
Manganese (μg/l)	< 2 - 230
Iron (μg/l)	< 2 - 300

Source: Plummer 1981.

[a] For the ranges shown, the maximum value reflects the sum of the highest concentrations of constituents in the carrier water and the maximum leachate concentrations.

unavoidable sampling contamination, none of the organic constituents listed among the 129 priority pollutants was detected (e.g., below detection limits) in either simulation run. Several trace metals were reported at low concentrations, as shown in Table 2-6.

Based upon the vertical and horizontal migration of ground water into the Madison Formation, the mineral characteristics of Madison or Crook County well-field source water is expected to vary over the project lifetime. A TDS level of up to 910 mg/l and an SO_4 level of up to 460 mg/l could be reached in the Crook County well field; a TDS level of up to 560 mg/l and an SO_4 level of up to 170 mg/l could be reached in the Niobrara County well field (WCC 1980a). As shown in Table 2-7, under worst case conditions the water fraction of the coal slurry is estimated to reach a TDS level of 1560 to 1910 mg/l and an SO_4 level of 790 to 1100 mg/l, and exert a BOD_5 of 125 to 175 mg/l (WCC 1981a).

The chemical characteristics of the source coal are described more completely in the Surface Water Quality Technical Report (WCC 1981a). Tables 2-8 and 2-9 present a summary of the characteristics of coal samples taken from the Wyodak Seam in Campbell County, Wyoming.

Analyses for trace metals were also performed on an ash sample of the Jacobs Ranch coal sample used in simulation runs (Commercial Testing and Engineering Co. 1980). A comparison of these results with the range in concentrations reported by the U.S.G.S. (1980) and Drever et al. (1977) for Wyodak seam coal in Campbell County shows that the sample used in the simulation runs was approximately equal to or less than the reported literature values, with the exception of the following elements, which were present at higher concentrations in the simulation sample: As (25 ppm); Cu (910 ppm); N (110 ppm); F (420 ppm); Sn (11 ppm); Zn (390 ppm); and U (9 ppm).

The temperature of slurry in the proposed pipeline system can be approximated by the mean annual temperature for states through which the pipeline passes (Folmer 1980). Table 2-10 presents these estimated slurry temperatures for low and high flow cases. Estimated water quality alternation is then presented for each spill type under each flow condition.

TABLE 2-6

COMPARISON OF PROJECTED CONCENTRATIONS OF PRIORITY POLLUTANTS TO EXISTING STANDARDS AND CRITERIA

			U.S. EPA (1980b) Water Quality Criteria for Toxic Pollutants (µg/l)		
			Freshwater Aquatic Life		
Parameter	Maximum Projected Concentration[a] (µg/l)	Drinking Water Standards[b] (µg/l)	Maximum	24-Hour Average	Human Health
Arsenic (As)	2 - 12	50	440	c	d
Beryllium (Be)	1 - 2	c	c	c	d
Cadmium (Cd)	4 - 10	10	e	f	10
Chromium (Cr)	3 - 27	50	21	.29	50
Copper (Cu)	20 - 90	1000	6	5.6	c
Cyanide (Cn)	20	200	52	3.5	200
Gold (Au)	2	c	c	c	c
Lead (Pb)	1 - 130	50	h	i	50
Mercury (Hg)	2 - 28	2	0.0017	0.00057	0.144
Molybdenum (Mb)	14	c	c	c	c
Nickel (Ni)	2 - 110	c	j	k	13.4
Selenium (Se)	1 - 20	10	260	35	10
Silver (Ag)	3 - 10	50	1	c	50
Thallium (Th)	1 - 5	c	c	c	13
Tin (Sn)	8 - 10	c	c	c	c
Zinc (Zn)	10 - 50	5000	m	47	c
Bis(2-Ethylhexyl) phthalate	5 - 40	c	c	c	15,000
Methylene Chloride	5 - 17	c	c	c	c

[a] Maximum reported concentrations. Refer to Surface Water Quality Technical Report (WCC 1981a), Table 1-24.

[b] U.S. EPA 1980a; all are primary drinking water standards except for copper and zinc which are secondary drinking water standards.

[c] Numerical criteria for maximum permissible level have not yet been established.

[d] "For the maximum protection of human health from the potential carcinogenic effects due to exposure of (this chemical) through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time." (U.S. EPA 1980b) The water quality criteria include estimated concentrations representing different risk levels to human health, but these are presented for information purposes only and do not represent an EPA judgment on an "acceptable" risk level.

[e] $e^{(1.05[\ln \text{hardness}]) - 3.73}$

[f] $e^{(1.05[\ln \text{hardness}]) - 8.53}$

[g] $e^{(0.94[\ln \text{hardness}]) - 1.23}$

[h] $e^{(1.22[\ln \text{hardness}]) - 0.47}$

[i] $e^{(2.35[\ln \text{hardness}]) - 9.48}$

[j] $e^{(0.76[\ln \text{hardness}]) + 4.02}$

[k] $e^{(0.76[\ln \text{hardness}]) + 1.06}$

[l] $e^{(1.72[\ln \text{hardness}]) - 6.52}$

[m] $e^{(0.83[\ln \text{hardness}]) + 1.95}$

TABLE 2-7

ESTIMATED DEWATERING PLANT EFFLUENT WATER QUALITY UNDER VARYING PROJECT CONDITIONS

	Constituent	Initial Concentration (mg/l)[a]	Concentration After 50 Years (mg/l)
Typical Conditions	TDS	900 - 1300	960 - 1310
	SO_4	425 - 750	467 - 757
	Cl	50 - 70	50 - 70
	BOD_5	125 - 175	125 - 175
Extreme Conditions[b]	TDS	1500 - 1900	1560 - 1910
	SO_4	750 - 1075	792 - 1082
	Cl	50 - 70	50 - 70
	BOD_5	125 - 175	125 - 175

Source: Plummer 1980b.

[a] A function of well field water quality, quantity of leached constituents, and coal processing procedures (e.g., source mine, coal storage conditions, and storage duration).

[b] Worst-case estimates, occurring a minimum percentage of the time.

TABLE 2-8

TRACE ELEMENTS PRESENT IN NINE COAL ASH SAMPLES TAKEN FROM THE WYODAK SEAM IN CAMPBELL COUNTY, WYOMING

Element	Reported Range in Concentration (ppm)[a]	Element	Reported Range in Concentration (ppm)[a]
Silver (Ag)	0.0	Neodymium (Nd)	0.0
Arsenic (As)[b]	1.0-3.0	Nickel (Ni)	20.0-70.0
Gold (Au)	0.0	Lead (Pb)	30.0-40.0
Boron (B)	300.0-700.0	Palladium (Pd)	0.0
Barium (Ba)	3000.0-7000.0	Phraseodymium (Pr)	0.0
Beryllium (Be)	0.0-5.0	Platinum (Pt)	0.0
Bismith (Bi)	0.0	Rhenium (Re)	0.0
Cadmium (Cd)	1.0-1.4	Antimony (Sb)[b]	0.1-0.7
Cerium (Ce)[b]	0.0	Scandium (Sc)	15.0-30.0
Cobalt (Co)	15.0-30.0	Selenium (Se)[b]	0.7-6.7
Chromium (Cr)	70.0-100.0	Samarium (Sm)	0.0
Copper (Cu)	104.0-216.0	Tin (Sn)	0.0
Erbium (Er)	0.0	Strontium (Sr)	700.0-2000.0
Europium (Eu)	0.0	Tantalum (Ta)	0.0
Fluorine (F)	45.0-65.0	Tellurium (Te)	0.0
Gallium (Ga)	20.0-50.0	Thorium (Th)[b]	3.0-3.3
Gadolinium (Gd)	0.0	Titanium (Ti)	0.0
Germanium (Ge)	0.0	Thulium (Tm)	0.0
Hafnium (Hf)	0.0	Uranium (U)	0.2-0.97
Mercury (Hg)[b]	0.08-0.29	Vanadium (V)	150.0-300.0
Indium (In)	0.0	Tungsten (W)	0.0
Lanthanum (La)	70.0-100.0	Yttrium (Y)	30.0-70.0
Lithium (Li)	25.0-48.0	Ytterbium (Yb)	3.0-7.0
Manganese (Mn)	190.0-500.0	Zinc (Zn)	36.0-218.0
Molybdenum (Mo)	0.0-15.0	Zirconium (Zr)	150.0-300.0
Niobium (Nb)	20.0-30.0		

Source: U.S. Geological Survey 1980.

[a] Concentrations measured by spectrographic analysis of ash samples.

[b] Whole coal.

TABLE 2-9

TRACE ELEMENT CONTENT OF COAL SAMPLES TAKEN FROM THE BLACK THUNDER MINE, WYOMING

Element	Concentration[a] (ppm)	Element	Concentration[a] (ppm)
Arsenic (As)	0.02-1.0	Mercury (Hg)	0.04-0.37
Beryllium (Be)	0.09-3.6	Molybdenum (Mo)	1-5.3
Cadmium (Cd)	F0.3-2.0	Lead (Pb)	4-19
Copper (Cu)	3-26	Uranium (U)	0.06-3

Source: Drever et al. 1977.

[a] Concentrations measured in samples taken from coal seam at depths of 79 to 146 feet.

TABLE 2-10

ESTIMATED COAL SLURRY TEMPERATURE

State	Temperature (°C)
Wyoming	7.8
Nebraska	9.2
Colorado	7.8
Kansas	13.1
Oklahoma	15.6
Arkansas	15.6
Louisiana	19.2

Chapter 3

SPILL MOVEMENT AND FATE

3.A RECEIVING WATER IMPACTS

The movement and fate of slurried coal and its impact on water quality parameters in the receiving waters depends on numerous factors, particularly the physical, chemical and biological characteristics of the receiving waters, the physical and chemical characteristics of the slurry and the nature of the spill.

The following is a description of the physical factors which affect the transport and settling of coal contained in the spill. In this discussion transport is defined as the combination of the effects of movement by mean currents (referred to as advection) and by turbulence and secondary currents (referred to as dispersion). This discussion is divided into receiving water types, first considering spills in a stream or river and then spills into an impoundment such as a lake or reservoir.

3.A.1 STREAMS AND RIVERS

An important factor affecting the dynamics of a spill in a river or stream is the magnitude of the spill flow (typical units are cubic feet per second, [cfs] compared to the stream flow. The discussion of the nature of spills is given in two parts, considering first the case where the streamflow is much larger than some characteristic flow (e.g., the maximum) associated with the spill whereas the second part deals with situations where the streamflow is much less than the characteristic flow.

High Background Flow Conditions

High background flow conditions are when the background streamflow is much larger, perhaps by an order of magnitude, than the maximum spill flow. Under these conditions the spill influences the flow field (i.e., circulation and turbulence) only in a zone near where the spill occurs. This zone is commonly referred to as the near field.

The near field mixing of the slurry with the receiving water is dominated by the interaction of the momentum and buoyancy of the slurry with the receiving water. In this zone, therefore, the nature of the spill (e.g., the size and orientation of the rupture, the proximity of the rupture to the receiving water, and the momentum of the discharged slurry coal through the rupture) are quite important. In this zone there could be very intense local mixing (e.g., in the form of a "boil" region) if the spill caused the slurry to issue into the receiving water as high velocity jets. On the other hand, a small rupture in a line could cause only a moderate seep into the stream. Thus the near field size and mixing could vary considerably depending on the nature of the spill.

In the far field, i.e., beyond the near field, the spill has little effect on the stream hydraulics, and it is commonly assumed that the mean current is approximately equal to that upstream of the spill. Also, because the momentum and buoyancy of the spill have been reduced by mixing in the near field, the coal is advected and dispersed by the mean and turbulent ambient conditions.

In general coal will disperse or spread in the vertical, transverse, and longitudinal directions. The rate of spreading will depend on such factors as the ambient turbulence (related to streamflow, depth, and channel roughness) and secondary currents (strongly associated with stream morphology).

The importance of the various directional dispersion processes varies from case to case. If the width and/or depth of the stream or river is large compared to the scale of the near field mixing zone, it may take some distance downstream before the plume created by the spill becomes vertically or laterally well mixed. For the selected scenarios the water depths are less than about 10 feet and vertically well mixed conditions are likely to occur in the near field, particularly in the cases of the spills caused by a complete rupture of the pipeline. If the plume becomes completely mixed over the stream cross-section then longitudinal dispersion may be the only effective dispersion process.

In addition to advection and dispersion of the coal, an important feature influencing the fate of coal from a spill is the deposition or settling out of the coal onto the stream bed. Major factors governing the settling rate and areal distribution of settled material are the characteristics of the coal particles (e.g., particle size, shape, specific gravity) and the structure of the flow in the river which may cause material to remain in suspension, may resuspend previously deposited material, or may cause movement of coal along the bed.

The fate of materials from a spill will depend strongly on whether the material settles or remains in suspension. Suspended materials will be advected downstream, disperse, and possibly settle in more tranquil downstream areas where the velocity decreases. Thus, the time scale of the water quality effects in the water column is dependent primarily on the travel time in the river.

The fate of the settled material is less clear and depends on the nature of the existing streambed and the subsequent streamflow record following the spill. Since the coal is lighter than many sediments (e.g., sand) there will be a tendency for the coal to remain near the surface of the streambed, however, mixing with the background sediments is also likely to occur. Subsequent high flow conditions, during spring for example, may resuspend or move the coal and possibly the associated sediments as bedload downstream. Thus, the coal may migrate downstream in both suspended and settled modes and could remain in the system for some time (e.g., on the order of years).

Low Background Flow Conditions

Low background flow is defined as a streamflow which is much less than some characteristic flow (e.g., the maximum spill flow) associated with the spill. In this case the spill flow causes an increase in water depth, streamflow, and velocity which, in the form of a hydrograph, propagates downstream. The shape of this hydrograph would depend on the volume, duration and flow history of the spill and stream characteristics (e.g., stream geometry, slope and background flow). In general, less dilution of the coal and other water quality parameters would be expected in the low background flow case than in the high background flow case.

Under low flow conditions the advection, dispersion and deposition of coal is quite complex because the volume and deposition of the spill could have a substantial effect on the steam hydraulics and channel geometry, which, in turn, would influence further deposition. In a worst-case scenario, the deposition of coal could create some partial or complete damming of a small stream. This material might then be moved downstream either as suspended or bedload transport by subsequent high streamflow events. Again, as discussed previously under high background streamflow, some of this material might reside in the stream system for a number of years. Of course, deposit of coal near the spill site could make cleanup more feasible.

3.A.2 LAKES AND RESERVOIRS

The fate of slurry spill coal that enters a lake is much different from that of coal that enters a stream. In general, a lake has less energy to maintain the coal in suspension and transport it than a stream or river has. Consequently, coal deposited in a lake will likely remain for a longer period of time and be less subject to natural erosion, dispersion, and degradation.

The processes affecting a spill can be distinquished by lake size. Spills in both small and large lakes are discussed below.

A small lake (both in volume and depth) could be considered a separate impoundment or run-of-the-river reservoir in which the detention time is less than the characteristic settling time of the finer coal fractions. In this case some of the coal could likely be transported through the reservoir as a plug flow or become well mixed within the impoundment. In either case some of the fine fractions will be transported and dispersed through a large portion of the water body and possibly be discharged downstream over a period of time similar to the detention time. The coarser fractions would settle to the bottom of the impoundment and be subject to bedload movement or resuspension depending on the subsequent hydraulic conditions in the lake. For example, for a run-of-the-river reservoir, previously settled coal could be resuspended during high inflow conditions (e.g., spring freshets).

Larger lakes, which could be separate impoundments or large run-of-the-river lakes, may be characterized by vertical stratification in the summer and numerous other physical processes (e.g., internal waves, withdrawal layers associated with releases) which affect the movement and fate of coal entering the lake from a spill. For example, the following might be a typical sequence of events if the spill were to enter the reservoir from a tributary during a period when the lake was stratified. Initially, as the flow velocity decreases in the backwater portion of the tributary and in the area where the tributary enters the lake, the coarser fractions of coal could settle. Upon entering the lake the coal slurry plume could sink and form a density current which would move along the bottom of the lake entraining ambient water. If the density of the current approached ambient density, movement of the slurry mixture would proceed horizontally as a shallow intrusion into the lake. Otherwise, the slurry mixture would extend down to and move along the bottom of the reservoir. The movement of such density currents are relatively slow compared to streamflow advection and could take several weeks to reach a discharge or withdrawal point of the lake. During and after this process there would be other factors (e.g., dispersion processes associated with the interaction of internal wave activity with the bottom) which would influence the ultimate fate of the material.

If the lake is large enough and withdrawal does not cause short circuiting of spilled material through the lake, it is likely that most or all of the coal will settle out either in the area near where the spill entered the reservoir or further into the reservoir proper. This material, once settled, could remain in the lake for a very long time and become part of the permanent sediment structure of the lake bottom. On the other hand, certain events, such as episodic events associated with strong meteorological forcing (e.g., storms) could ultimately cause settled material to resuspend and migrate within the reservoir or perhaps be transported out of the reservoir. In summary, the dynamics of material transport in a lake could be quite complex, but it can be concluded that coal could likely remain in lakes (particularly larger lakes) for a very long time and perhaps become part of the permanent sediment structure.

3.B GROUND WATER IMPACTS

Along the pipeline route, ground water is a major source of water for domestic, irrigation, and stock watering needs. Therefore, the changes that would occur to ground-water quality should a spill occur were investigated. The mechanisms of water movement following a rupture are described below. These machanisms are relative to water movements for both subsurface spills and surface or terrestrial spills where the slurry water has infiltrated the substrate.

After the pipeline has been broken, the coal slurry would move away from the break. Most likely, the slurry mixture would first move along the backfilled pipeline trench where the soil or rock is less compacted and therefore more permeable. In addition, the slurry would also tend to move downward under the influence of gravity, outward from the spill into the more permeable soils and down the hydraulic ground-water gradient. The soil will likely filter out much of the coal in the vicinity of the spill, leaving only the liquid portion of the slurry to continue to move away from the spill. Clogging of the soil pores by the coal would also probably slow the migration of the slurry away from the spill.

The quantity of spilled water that would enter the ground-water system would depend on many factors. The major factors are:

- the infiltration rate and infiltration capacity of surficial soils and subsoil
- the depth to the ground water table
- the climatic conditions before, during, and after the spill
- the possible reduction of the infiltration rate by clogging of the pores with coal particles
- any mitigating actions undertaken.

The quality of the water that eventuallyt reaches the ground-water table would be determined by the quality of water that drains from the coal and by the chemical reactions that occur as the slurry water passes through the unsaturated zone. The most important chemical processes in the unsaturated zone are likely to be cation exchange reactions, absorption reactions, dissolution-precipitation reactions, and chelation (e.g., complex formations with organic and inorganic ligands). Trace metal and dissolved organic concentrations are likely to be much less than in the coal slurry water as a result of selective absorption, precipitation, and cation exchange reactions.

3.C TERRESTRIAL IMPACTS

A spill on land can be evaluated by considering first the conditions near the pipe rupture and then conditions at some distance from the rupture.

Near the rupture the characteristics of the spill are linked strongly with the type of rupture. For example, under certain conditions, such as an orifice rupture, a high velocity jet could discharge material into the air. This material could then be transported, to some extent, downwind before falling back to the ground. On the other hand, a high velocity jet directed towards the ground could cause local erosion and create gullying.

Beyond this region near the rupture, the slurry will move downgradient in the form of a mudflow. The nature of this flow is highly dependent on the land surface slopes and roughness, the tendancy of the flow to channelize as opposed to flowing as a sheet, and the potential for natural impoundment.

As the flow moves downgradient some material may deposit out; in general, one expects the coarser fractions to deposit out initially with smaller fractions settling out over time. At some distance from the spill perhaps only the very fine fractions of coal will remain in suspension.

Eventually other processes will become important. These include possible mergers of the flow with a receiving water body (stream or lake, for example), evaporation of water from the flow, and/or depletion of the flow by infiltration into the underlying soil. In the latter case the slurry water could continue downward through the subtrate and into ground-water aquifers. The mechanisms for this process are discussed in Section 3.B. The ultimate fate of the settled coal will depend on factors such as transport by wind to adjacent areas, movement by surface runoff associated with subsequent precipitation, and mixing with existing sediments.

These different processes are important over different time (and therefore space) scales and the significance of any one factor is highly site-specific. Thus, it is difficult to characterize in general such effects as the areal coverage of settled material from a terrestrial spill.

3.D PIPELINE FLOW

In the event of a pipeline rupture, a portion of the coal would settle out of the slurry as its velocity decreases during draindown. The coal content and quantity of slurry remaining in the pipeline would be difficult to predict as both are dependent on several site specific variables. The most significant of these variables include size of the rupture, rate of slurry discharge, slurry density, slope of pipeline, amount of hydraulic head, and velocity of slurry movement, all of which are interrelated.

As draindown occurs, the line flow velocity decreases and the heavier coal particles begin to settle out at velocities less than 4 feet per second (fps). The quantity of coal that settles out depends primarily on the rate of slurry discharge. Generally speaking, the greater the spill rate, the lower the quantity of coal remaining in the pipeline, due to the maintenance of higher flow velocities during draindown.

Chapter 4
IMPACT ASSESSMENT

4.A APPROACH

Due to the extensive length of the pipeline and the diverse nature of environments that could be affected by a coal slurry spill, the potential impacts were assessed in general terms and by using eight spill scenarios situations in major types of environments located along the pipeline route. The scenarios were selected using the following criteria:

Habitat Type

Representative sites should include both terrestrial and aquatic habitats.

Flow Type

To account for the variability in dilution and dispersion of potential spills associated with different flow regimes, sites should include: small perennial creek, medium-size river, major river, bayou waterway, and reservoir.

Vegetation Type

Due to potential sensitivity of terrestrial vegetation, sites should include examples of wetland, prairie, and forest vegetation communities.

Spill Type

Because the slurry flow rate varies (decreases) from the beginning to the end of a given alternative route, spill sites should be geographically distributed along the general project route, and selected from both the proposed and alternative routes, in order to represent the range in potential spill volumes. For a given spill area, the site should be selected at a topographic low point in order to represent the worst case spill rate and volume.

Biological Sensitivity

Selection of sites should incorporate specially identified sensitive habitats, including active fisheries and Arkansas Darter habitat.

Institutional Sensitivity

Sites should include a designated State Scenic River or unique recreational areas, in order to evaluate aesthetic or recreational sensitivity. A site located upstream of a municipal water intake and/or municipal reservoir should be selected to evaluate potential public health effects upon drinking water supplies. Areas of special concern, as indicated by state agencies, should be considered in site selection.

In the ecological impact analysis emphasis was placed on biota believed to be most sensitive to the various physical and chemical effects anticipated at the spill locations. The various physical and chemical spill data, upon which the biological impacks are based, have been developed from the spill movement models and associated assumptions.

The environmental impacts at each scenario site were assessed by first determining maximum spill volumes and slurry movements through the surface water, ground-water, and terrestrial regimes and then analyzing the effects of coal slurry on the areas of those regimes that would be affected.

Computer models were used to estimate maximum spill rates and volumes at each scenario location for both a complete break and orifice-type rupture. The results, given in total volumes, tonnages, and times to spill, were used to model the spill's movements through surface waters at the river and lake crossing scenarios, and overland movements for the terrestrial scenarios. Insufficient near-surface geological and hydrogeological data was available for areas along the pipeline route to accurately model movements of a coal slurry spill to ground-water aquifers. Therefore, a hypothetical spill situation using the characteristics of a major aquifer type was modeled to determine sub-surface spill movements in a worst-case scenario.

The conclusions of the modeling exercises were then used to quantify the surfacewater quality and ecological impacts for the aquatic spill scenarios and the ground-water quality and ecological impacts for the terrestrial spill scenarios.

4.B SPILL SCENARIOS

4.B.1 SCENARIO DESCRIPTIONS

Table 4-1 presents a list of the sites selected for simulated slurry spill analysis. These eight sites incorporate the selection criteria as described in Section 4.A. Table 4-2 indicates the criteria applicable to each site. These scenarios relate principally to terrestrial or surface water sites. The effect of potential spills on groundwater quality has been evaluated for three aquifer types (Section 3.B) using simulated spill rates.

4.B.2 SCENARIO SPILL MODELING

The following discussion describes the modeling techniques, methodology, and assumptions used in predicting maximum coal slurry spill volumes and movements at each of the scenario locations. The spill movements were modeled with respect to the probable extent of their flow through three components of the physical environment: surface water, groundwater, and terrestrial.

Spill Volumes

Methodology. Once a leak has been detected and the decision to shut down made,[a] the quantity and rate at which material is lost can be estimated.

A computer model was used to estimate the rates at which a line full of slurry would drain, and the total volume of liquid and ton of solids that might be spilled if the line were ruptured at each scenario location. Inputs to the model were profile and breakpoint mileposts and elevations, pipe inside diameter, slurry density and saturated volume concentration, a breaktype (either an orifice hole type or complete rupture), and the upstream and downstream pump station locations.

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[a] In not all cases is it best to shut down the pipeline immediately after a leak detection. A skilled operator can minimize leak potential in some parts of the pipeline by understanding the hydraulic implications of shutting down. This case will not be covered in this report because of the unknowns involved. In general, the decision of the operators should improve the spill potential scenario.

TABLE 4-1

SPILL SCENARIO LOCATIONS

1. North Platte River, Nebraska. Approximately milepost PMB-203 of Proposed Action. USGS Station #06686000 near Lisco, Nebraska is approximately 15 miles downstream from crossing.

2. Sand Creek, Oklahoma. Approximately milepost MB-348 of Market Alternative. USGS Station #07174600 at Okesa, Oklahoma is approximately 10 miles downstream from crossing.

3. Recreational area, Oklahoma (Tallgrass Meadow/Bottomland Forest). Approximately milepost PMB-800 of Proposed Action.

4. Illinois River, Oklahoma. Approximately milepost MB-438.5 of Market Alternative. USGS Station #07196500 near Tahlequah less than 1/2 mile upstream from crossing.

5. Cedar Bluff Reservoir (unnamed tributary), Kansas. Approximately milepost C-491 of Colorado Alternative. USGS Station #06861500 is located at Cedar Bluff Reservoir near Ellis, Kansas.

6. Saline River, Arkansas. Approximately milepost PM-1118 of Proposed Action. USGS Station #07363500 near Rye, Arkansas approximately 15 miles downstream from crossing.

7. Bayou Cocodrie, Louisiana. Approximately milepost PM-1338 of Proposed Action. USGS Station #07382000 near Clearwater approximately 15 miles upstream from crossing.

8. Bottomland-Hardwoods area, Louisiana. Approximately milepost PM(NW)-48 of New Roads Lateral.

TABLE 4-2

CRITERIA USED TO SELECT SPILL SCENARIO SITES

Criterion	Site 1	2	3	4	5	6	7	8
Habitat Type								
Aquatic Habitat	X	X		X	X	X	X	X
Terrestrial Habitat			X					X
Flow Type								
Small Perennial Creek		X						
Medium Size Stream				X		X		
Major River	X							
Bayou Waterway							X	
Reservoir					X			
Vegetation Type								
Wetland							X	X
Prairie/Forest			X					
Spill Type								
Representative Geographic Distribution	X	X	X	X		X	X	X
Biological Sensitivity								
Active Fishery					X	X		
Arkansas Darter Habitat		X						
Sensitive Habitat							X	X
Institutional Sensitivity								
State Scenic River				X			X	
Recreational Use			X	X	X			
Downstream Municipal Water Intake				X				
Area of Special Concern (indicated by state)			X	X	X	X	X	X

Outputs from the model were total spill volumes, tonnages, and reports of spill volume and coal tonnage versus time. An algorithm was developed to take into account possible settling of solids in the pipeline as velocities in the line drop below the solids deposition level. The solids settling algorithm consisted of a linear relationship between slurry-specific gravity and velocity for velocities less than four feet per second. Above four feet per second the slurry was assumed to be homogeneous. The velocities printed on the output listing are the velocities immediately upstream (UPS) and downstream (DS) of the break point. These velocities were used in the flowing slurry-specific gravity estimates.

In addition to the above, line pressure at the break point is tabulated versus time. Note that during draindown for the complete rupture cases the line pressure is zero, and for the orifice type ruptures the value is greater than zero.

Assumptions. Assumptions made in the drainage model were as follows:

- The frictional head losses as measured in feet of slurry for a given velocity are constant for the concentrations seen in the pipeline during draindown.
- The pipeline does not plug due to solids accumulation at the low points at low velocities.
- The solids settling algorithm discussed above was used.
- An extrapolation of steel wear rates versus velocity from existing data was made for use in determining the rate at which a hole in a pipe opened due to solid abrasion.
- The size of a hole in the steel pipe increases due to abrasion as a logarithmic function of the velocity of slurry flow through the hole.
- No drainage from horizontal pipe sections occurs.

For each spill location, a projected spill was produced for a complete rupture and an orifice type rupture. The complete rupture assumed that each pipe upstream and downstream of the breakpoint drained independent of the other. The orifice ruptures drained through a 3-inch hole. The 3-inch hole was selected as being a realisitic size based on equipment-caused holes such as a plow point, dozer, or grader blade or any other puncturing type apparatus.

Results. Figures 1 through 16 in the Appendix show the computed results of the two break types at each point. Figures 17 through 24 in the Appendix show the profiles upon which each case was based. These profiles were produced by ETSI as part of their system description and represent points taken at each 200-foot contour line on USGS 1:250,000 maps.

The output generated is summarized in Table 4-3. Of the complete break cases, the largest potential spill was at the Cedar Bluff Reservoir where 544,000 barrels of slurry containing 58,400 tons of saturated coal could be spilled if a complete pipeline rupture occurred. The spill would occur over a period of about 16 hours.

The smallest leak occurred at the Bayou Cocodrie area, where in the case of a 3-inch hole, 4000 barrels containing 100 tons of coal were lost.

Table 4-3 volumes are based on spills between two adjacent pump stations. No attempts have been made in this report to analyze the impact which placing valves between pump stations has on spill sizes.

Surface Waters - Streams and Rivers

Methodology and Assumptions. The analysis of the coal slurry spill used two different approaches (or classes of models) depending on the maximum flow rate of the spill compared to the background streamflow. These two approaches will be discussed separately.

High Stream Flow Conditions. When the maximum flow rate of the spill was less than 20 percent of the background stream flow it was assumed that the stream flow was unaffected by the spill except very near the spill itself (the near field). In other words, beyond the near field the coal was advected downstream at a speed equal to the ambient stream or river current. The ambient river current was assumed constant.

The spreading of the plume caused by the coal slurry spill was assumed to be primarily in the lateral or transverse direction because: the channel width was often large compared to the characteristic scale of the near field, and the

TABLE 4-3

SUMMARY OF EIGHT SPILL SCENARIOS

Site	Inside Pipe Diameter (in.)	Total[a] Volume (bbl)	Total Solids (tons)	Time to Spill (hrs)	Spill Type[b]
North Platte River	45.188	405,000	39,500	9.5	CB
Sand Creek	45.188	95,000	8,100	4.8	CB
Recreational Area	45.188	44,000	3,600	1.6	CB
Illinois River	39.376	52,000	5,200	1.0	CB
Cedar Bluff Res.	45.118	544,000	58,400	16.1	CB
Saline River	31.446	26,000	1,100	6.7	CB
Bayou Cocodrie	13.500	4,000	200	3.1	CB
Bottomland	25.500	51,000	1,400	24+	CB
North Platte River	45.188	393,000	24,700	24+	O
Sand Creek	45.188	92,000	1,700	23.0	O
Recreational Area	45.188	44,000	600	19.3	O
Illinois River	39.376	52,000	900	14.3	O
Cedar Bluff Res.	45.118	443,000	32,000	24+	O
Saline River	31.446	26,000	300	19.5	O
Bayou Cocodrie	13.500	4,000	100	5.0	O
Bottomland	25.500	31,000	500	24+	O

[a] Total volume is complete volume of spill if spill time is less than 24 hours. It is the spill at 24 hours if spill time is greater than 24 hours.

[b] Spill types are complete break (CB) or 3-inch orifice type (O).

depth of water was usually small compared to this same scale. It was also assumed that the transverse diffusion was more important than the longitudinal dispersion until the plume became fully mixed laterally.

The model used for these assumed conditions is referred to herein as the transverse diffusion model (see for example, Fischer et al. 1979), in which the coal concentration is given by

$$C\,(x,y,t) \;=\; \overset{\text{(Term 1)}}{\frac{\dot{M}(t)\,\exp-(kt)}{dU \quad 4\,D_y \frac{x}{U}}} \;\; \overset{\text{(Term 2)}}{\exp - \;\frac{Uy^2}{4D_y x}} \qquad (1)$$

where

C = depth mean concentration (M/L^3)

$\dot{M}(t)$ = spill rate of dry coal (M/T)

d = hydraulic depth (L)

U = stream current (L/T)

D_y = diffusion coefficient in transverse direction (L^2/T)

x = longitudinal coordinate (L)

y = transverse coordinate (L)

T_s = settling time scale (T)

k = inverse of settling time scale (T^{-1})

Term 1 in equation 1 represents the maximum centerline concentration (C_{max}), where the factor e^{-kt} reflects the effects of settling (to be discussed); term 2 represents the reduction of concentration in the transverse direction (i.e., off the centerline) and was used to estimate the plume width.

Figure 4-1 shows a schematic of the transverse diffusion model. The river is assumed to be rectangular in cross section with a hydraulic depth d and, as previously stated, a constant velocity U. The hydraulic depth was computed from

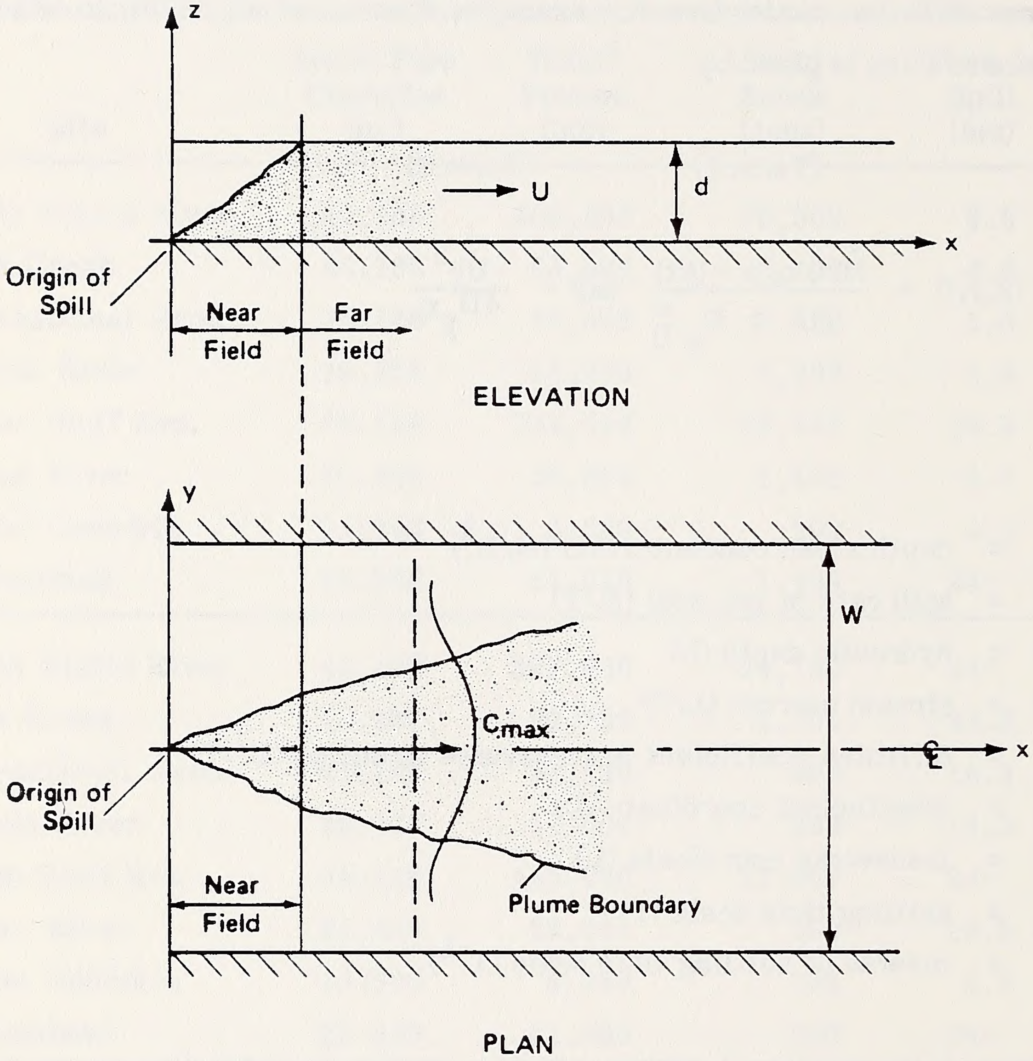


Figure 4-1. SCHEMATIC OF TRANSVERSE DIFFUSION MODEL USED

$$d = A/B \tag{2}$$

where A is the cross sectional area and B is the top width of the stream. These data were obtained from USGS current monitoring surveys.

The spill is assumed to occur at the midpoint and at the bottom of the channel. The spill rate M(t) is the rate of efflux of dry coal per unit time into the stream. This value was obtained from the PSI model results. Because the spill rate varied with time, it was assumed to be piecewise constant over the time intervals provided in the PSI output.

The lateral or transverse diffusion coefficient D_y was assumed to be given by

$$D_y \cong 0.15\, dU_* \tag{3}$$

where U_*, the shear velocity, is given by

$$U_* = \sqrt{\frac{f}{8}}\, U \tag{4}$$

where f, the friction factor, is primarily a measure of the roughness of the bed and can be related to such factors as the Chezy coefficent or Manning's roughness factor n.

Note that the transverse diffusion model only applies in the far field as shown in Figure 4-1. The near field customarily is assumed to extend on the order of 5 to 10 water depths downstream, depending on the depth of water and the nature of the spill.

The settling time scale T_s is given by

$$T_s = \frac{d/2}{W_s}$$

where W_s is the fall velocity of a given size of coal particle.

The fall velocity was computed for the size of interest using Stokes law, which takes into account the specific gravity of dry coal (Vanoni 1975). The particle size distribution (as provided by PSI) and the computed settling velocities are shown in Figure 4-2. In order to estimate the amount of settled material it is necessary to estimate the minimum particle size which could potentially settle. An approximate settling criterion adopted from Raudkivi (1976) is to assume that the minimum particle size which could potentially settle has a fall velocity which is approximately equal to the shear velocity. Thus Figure 4-2 could be entered as shown with the estimated shear velocity to yield the minimum particle size diameter which could settle and the percentage of material which is larger than this minimum diameter and therefore could potentially settle. The settling term e^{-kt} in equation 1 was corrected to account for the fact that all size fractions were not subject to settling.

Low Stream Flow Conditions. When the maximum spill rate was greater than 20 percent of the background flow it was assumed that the downstream river flow was affected by the spill. Under these conditions the spill was routed downstream using a simple flow routing method.

The flow routing method used was the "diffusion analogy" method described by Eagleson (1970) and given by

$$q(x,t) = \frac{\forall}{2(D_o)^{1/2}} \quad \frac{x}{t^{3/2}} \quad \exp - \left[\frac{(x-c_o t)^2}{4D_o t} \right] \qquad (5)$$

where

q = additional flow rate per unit width induced by the spill (L^3/LT)

$\forall$ = volume of slurry contained within a given time interval of the spill (L^3)

D_o = longitudinal diffusivity (L^2/T)

x = longitudinal coordinate (L)

t = time since discrete volume of slurry entered river (T)

c_o = celerity of routed wave (L/T)

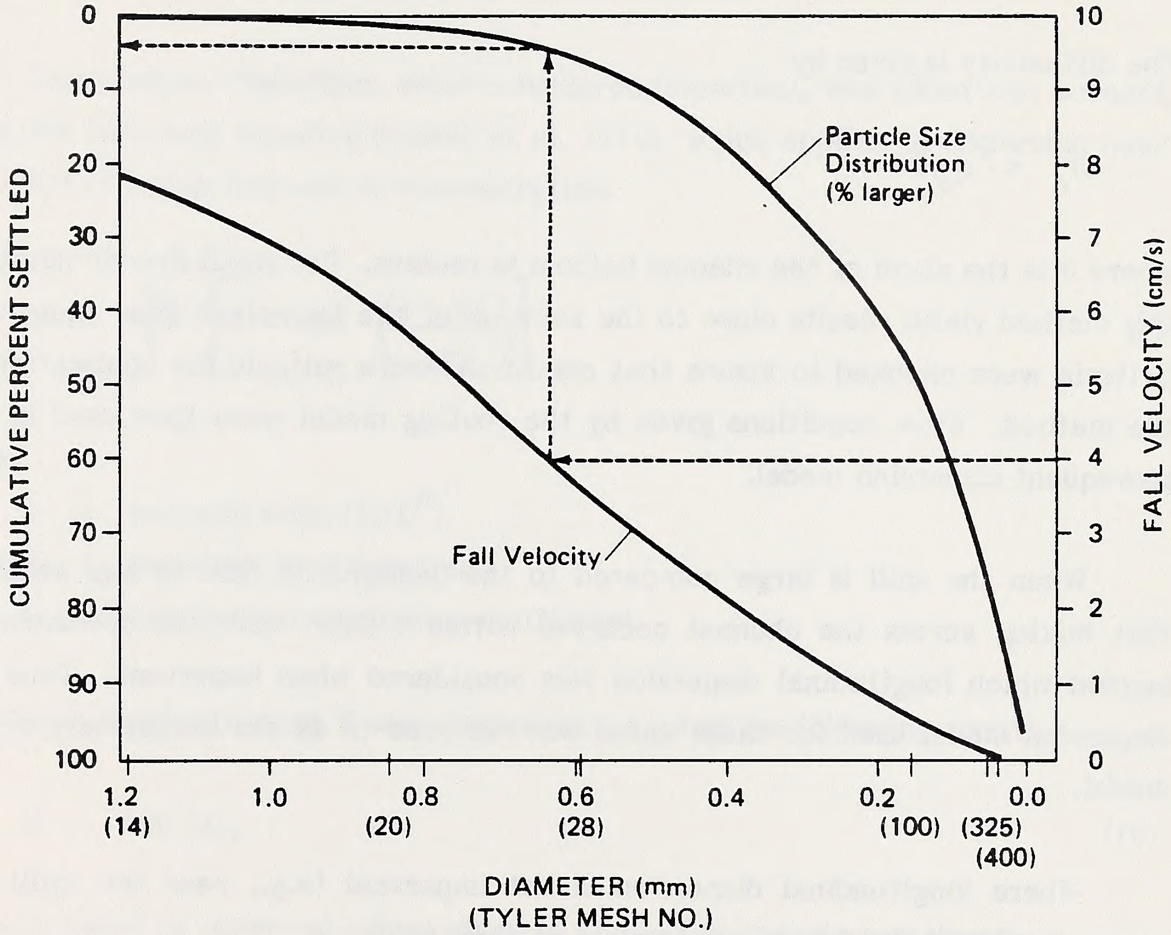


Figure 4-2. PARTICLE SIZE DISTRIBUTION AND SETTLING VELOCITY FOR COAL IN SLURRY LINE

The celerity of the routed wave is given by

$$c_o = 1.5 \frac{q_o}{d_o} \tag{6}$$

where q_o and d_o are the background unit flow rate and water depth.

The diffusivity is given by

$$D_o = q_o/2\theta$$

where θ is the slope of the channel bottom in radians. For small Froude numbers this method yields results close to the solution of the linearized flow equations. Criteria were checked to insure that conditions were suitable for application of the method. Flow conditions given by the routing model were then used in the subsequent dispersion model.

When the spill is large compared to the background flow it was assumed that mixing across the channel occurred within a short distance downstream, beyond which longitudinal dispersion was considered when important. Thus the dispersion model used for these cases was referred to as the completely mixed model.

Where longitundinal dispersion is not important (e.g., near the spill) the concentration is given by a simple mass balance as

$$C_o = \frac{C_p}{D} \tag{7}$$

where

C_o = downstream completely mixed concentration (M/L^3)
C_p = concentration in pipeline (M/L^3)
D = dilution

The dilution is given by

$$D = 1 + \frac{Q \text{ stream}}{Q \text{ spill}} \tag{8}$$

where

Q stream = upstream flow rate (L^3/T)
Q spill = spill flow rate (L^3/T)

Longitudinal dispersion, when considered important, was taken into account using the following equation (Fisher et al. 1979), which applies to dispersion near the front of a step increase in concentration.

$$C = \frac{C_o}{2} \left[1 - \text{erf} \left(\frac{x - Ut}{4Kt} \right) \right] \tag{9}$$

where

C = concentration (M/L^3)
erf = standard error function
K = longitudinal dispersion coefficient

The dispersion coefficient K was approximated using the following equation

$$K = 200 \, dU_* \tag{10}$$

which is based on observed values given in Fisher for streams and rivers.

A summary showing which dispersion model applied under given stream flow conditions and spill types is given in Table 4-4.

Results. The transverse diffusion and completely mixed models were applied to the various scenarios using the following input data:

- spill and slurry characteristics provided by PSI
- river hydraulic characteristics obtained from USGS current monitoring surveys.

TABLE 4-4

RIVER SCENARIOS - DISPERSION MODEL USED

Scenario No.	Stream or River	Stream flow	Complete Rupture	Orifice Rupture
1	North Platte	High	Trans	Trans
		Low	CM[a]	Trans[a]
2	Sand Creek	High	CM[a]	Trans
		Low	CM[a]	CM[a]
4	Illinois River	High	Trans	Trans
		Low	Long	Trans
6	Saline River	High	Trans	Trans
		Low	Trans	Trans
7	Bayou Cocodrie	High	Trans	Trans
		Low	Trans	Trans

Trans = Transverse Dispersion Model

CM = Completely mixed with Longitudinal Dispersion when important

[a] Includes flow routing.

Some of the more important background stream hydraulic characteristics are given in Table 4-5. The Mannings roughness coefficient used was 0.035 in all rivers except Bayou Cocodrie for which a value of 0.025 was used because of its relatively fine-grained bed material (silt).

The results of the dispersion and settling analysis for each scenario are presented in the form of figures and tables. Figures 4-3 through 4-7 show the predicted water column concentrations for each scenario generally at specific times closely following the spill, during which the estimated concentrations are likely to be at or near maximum. Because the spills are transient the concentrations at any given location during other times generally will be less than those given in the Figures. In some cases, when the spill rates are approximately constant, the estimated concentrations are over a time interval.

Also, the concentration presented is different depending on the model used. For the transverse diffusion model the concentration given is the depth-mean concentration along the centerline of the river, i.e., the maximum depth-mean concentration across the channel. For the completely mixed model, the concentration is the cross-sectional mean.

In order to get a more complete picture of the dynamic nature of the stream response to the spill, Tables 4-6 through 4-19 give, for selected cases, concentration versus time and distance downstream. In addition, estimates of plume width and settling are provided when appropriate.

It should be noted, as explained previously, that the models are field models and estimates become less certain near the spill. Thus, in some cases, obviously inaccurate predictions have been omitted from the figures or tables.

Spill Scenarios. Following is a brief discussion of each scenario. After the results are discussed by scenario, a summary integrating the results is presented.

Scenario 1 - North Platte River. Figure 4-3 shows the estimated predicted concentrations for selected times following the spill for the two spill types and under high and low flow conditions.

TABLE 4-5

BACKGROUND RECEIVING WATER CHARACTERISTICS

Scenario	River	USGS Gaging Station	Date of Current Survey	Flow Rate (cfs)	Hydraulic Depth (ft)	Width (ft)	Average Velocity (ft/sec)	Shear Velocity (ft/sec)
1	N. Platte,	06686000	6-4-71	11,450	4.9	596	3.92	0.276
	Nebraska		7-16-79	266	0.59	289	1.56	0.227
2	Sand Cr.,	07174600	4-7-78	317	1.35	73	3.22	0.406
	Oklahoma		1-24-78	2.1	0.46	5.46	0.84	0.129
4	Illinois R.,	07196500	8-13-79	16,300	11.0	343	4.33	0.390
	Oklahoma		10-17-78	152	1.2	90	1.41	0.182
6	Saline R.,	07363500	3-6-79[a]	11,400	9.4	946	1.28	0.117
	Arkansas		8-14-79	246	1.3	70	2.71	0.349
7	Bayou Cocodrie, Louisiana	07382000	9-24-79	1,900	10.5	238	0.76	0.049
			9-27-78	104	2.2	43	1.10	0.092

[a] For main channel only.

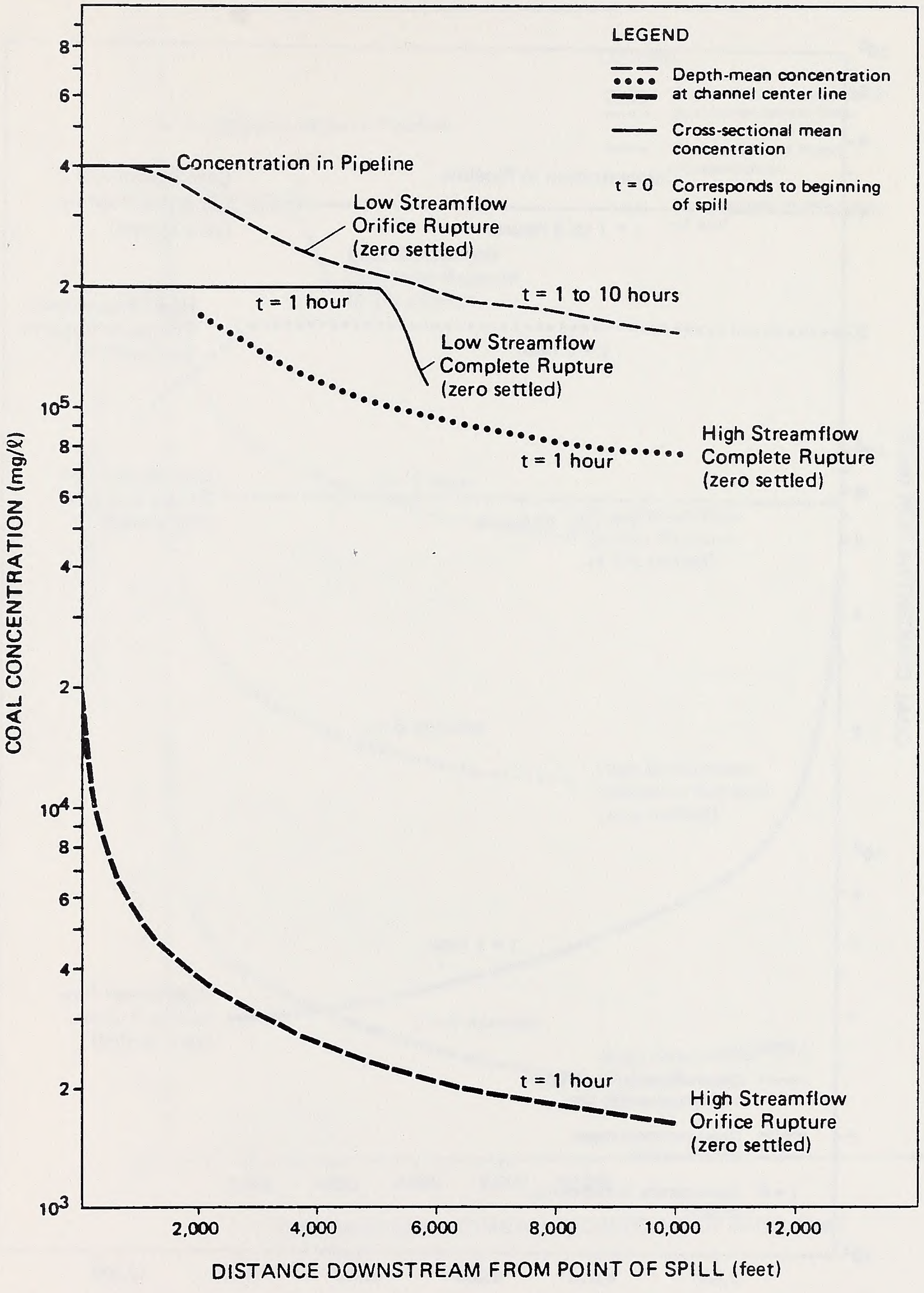


Figure 4-3. PREDICTED MAXIMUM COAL CONCENTRATION IN NORTH PLATTE RIVER, NEBRASKA (Scenario 1)

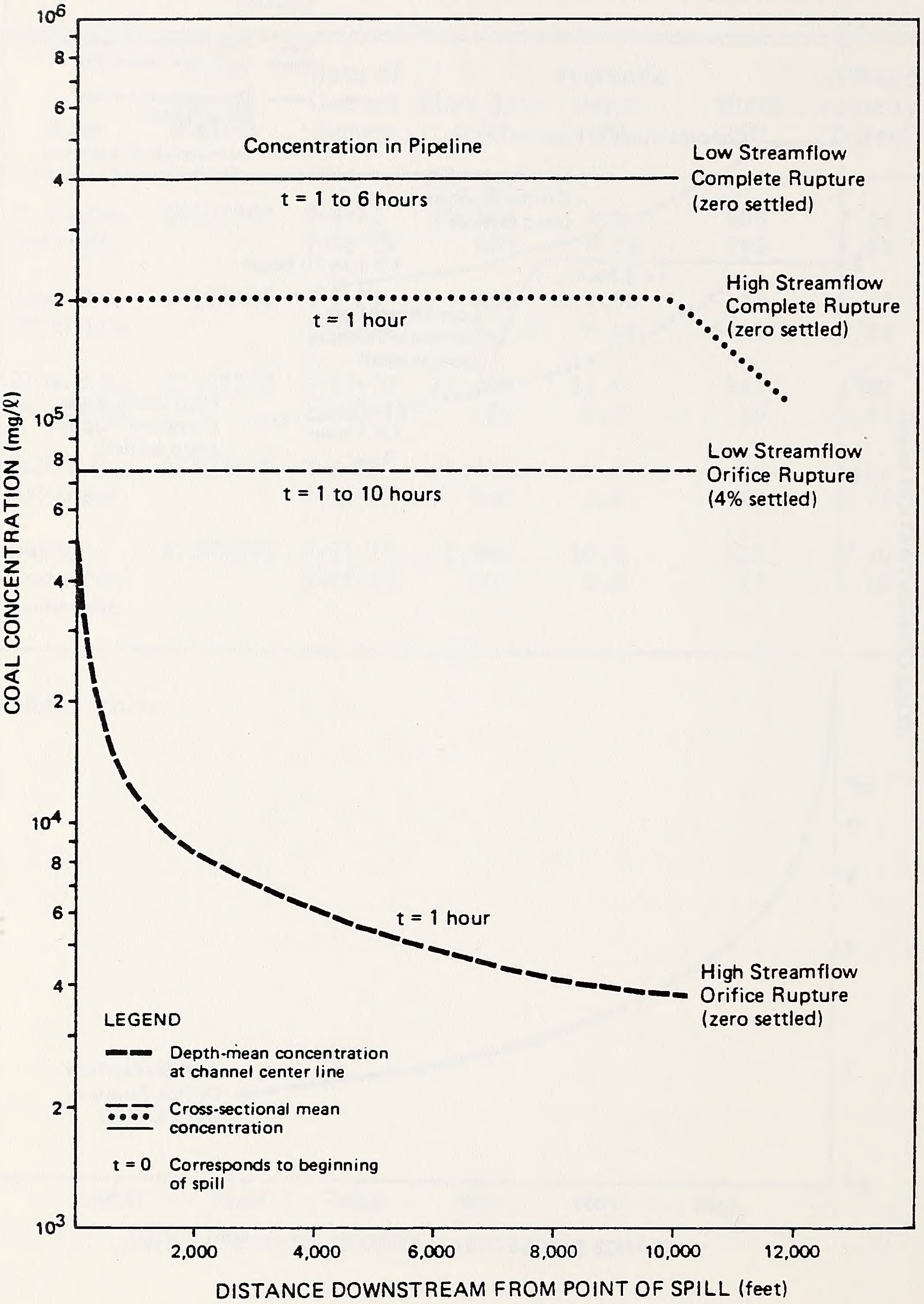


Figure 4-4. PREDICTED MAXIMUM COAL CONCENTRATION IN SAND CREEK, OKLAHOMA (Scenario 2)

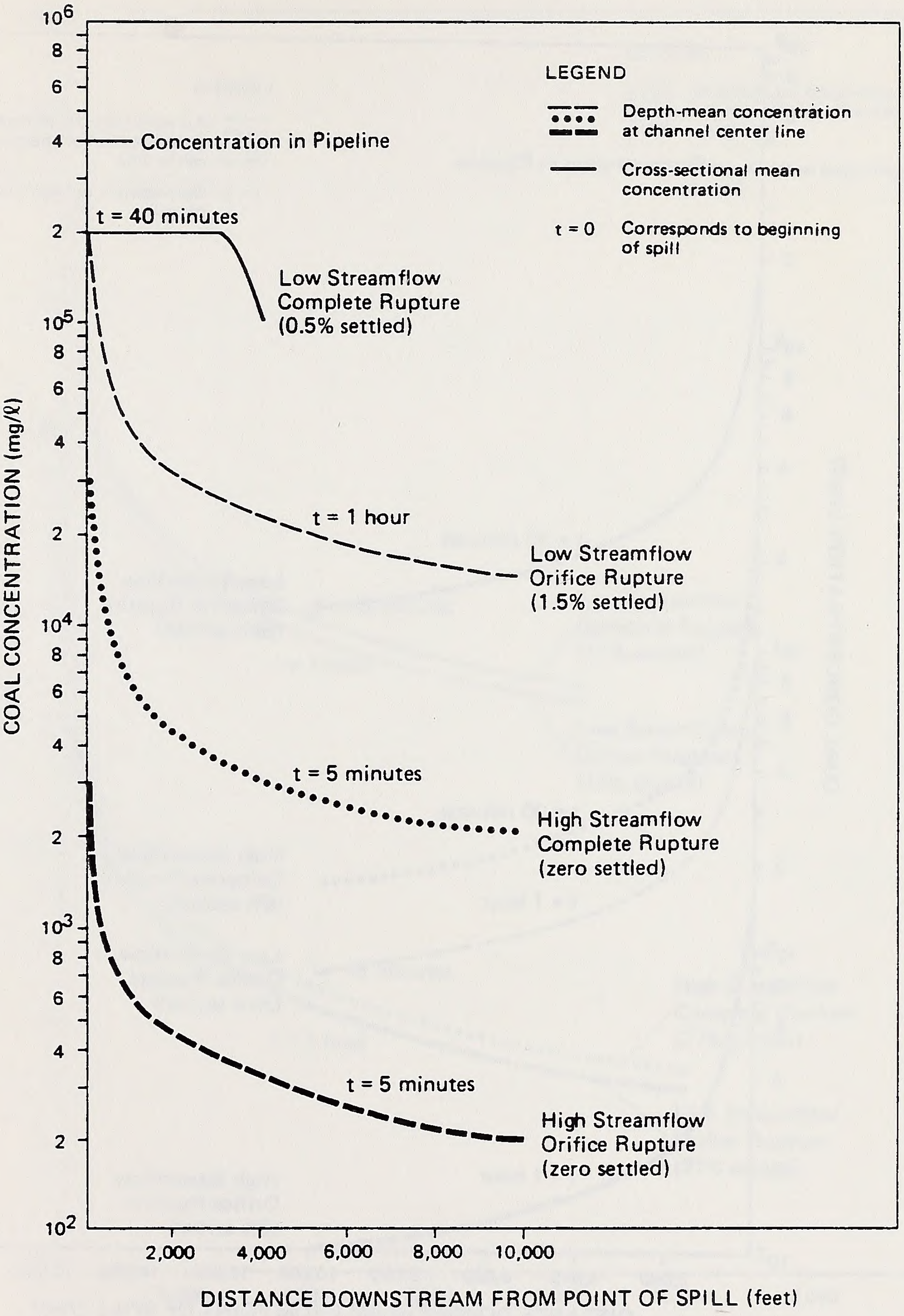


Figure 4-5. PREDICTED MAXIMUM COAL CONCENTRATION IN ILLINOIS RIVER, OKLAHOMA (Scenario 4)

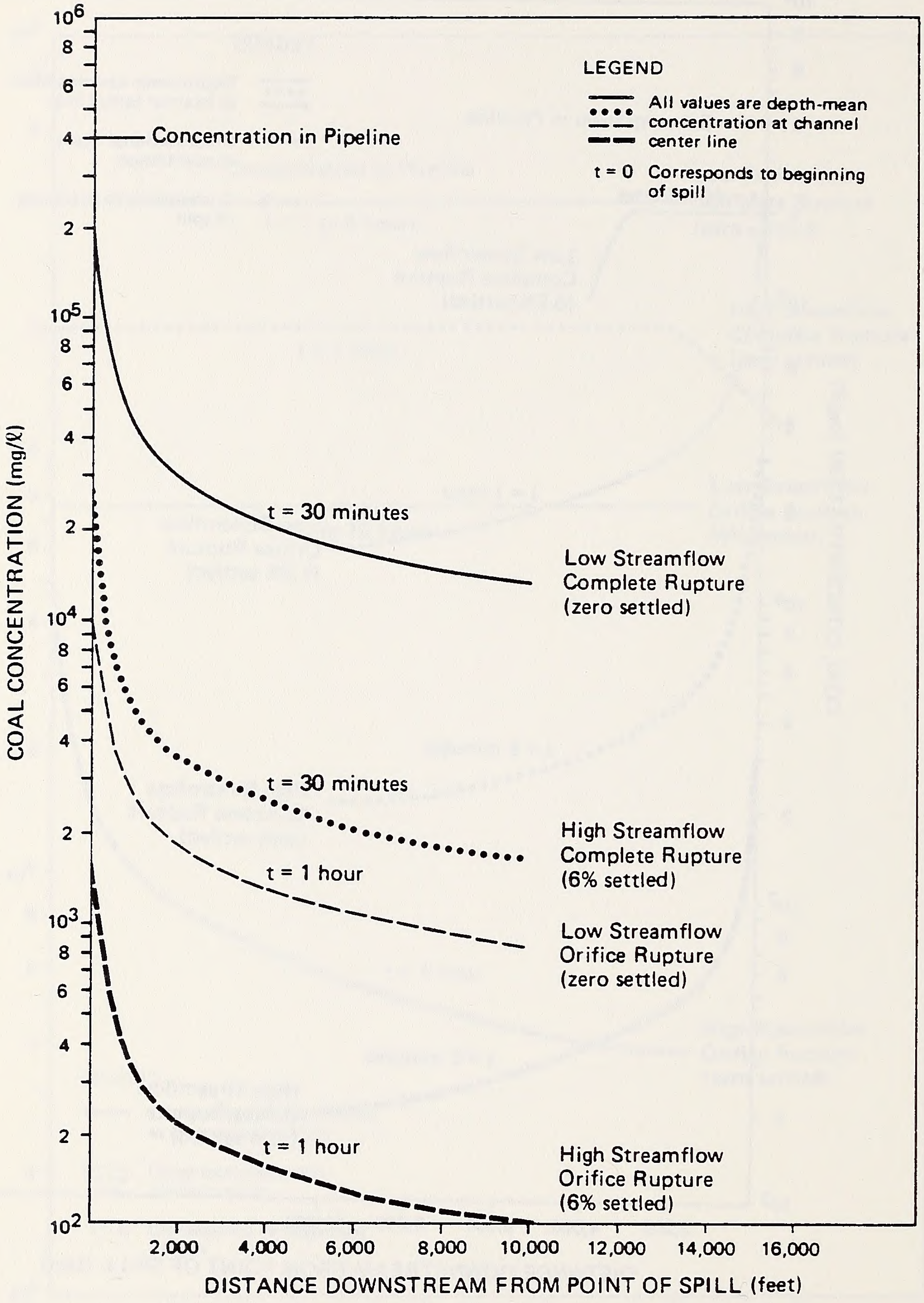


Figure 4-6. PREDICTED MAXIMUM COAL CONCENTRATION IN SALINE RIVER, ARKANSAS (Scenario 6)

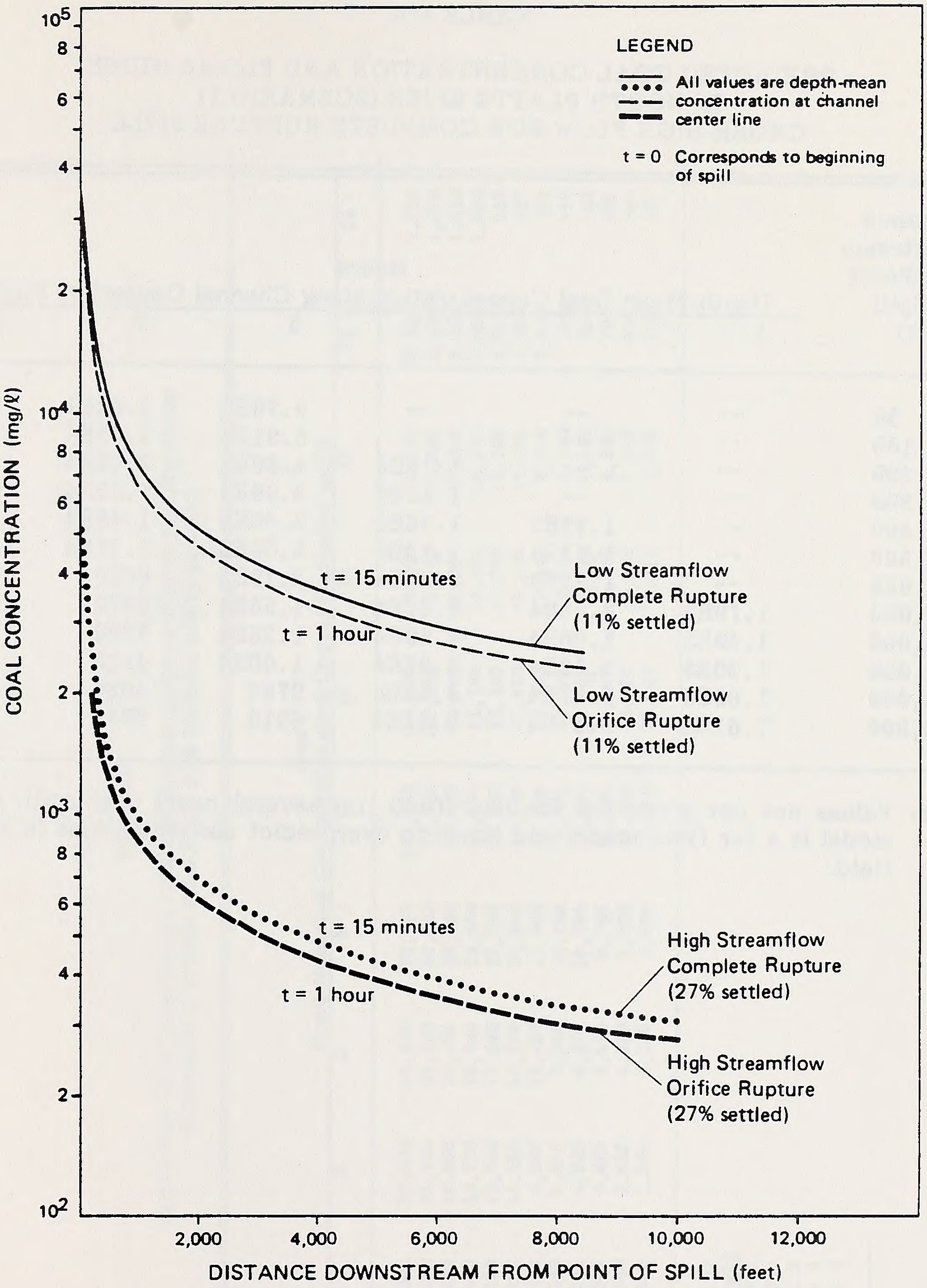


Figure 4-7. PREDICTED MAXIMUM COAL CONCENTRATION IN BAYOU COCODRIE, LOUISIANA (Scenario 7)

TABLE 4-6

PREDICTED COAL CONCENTRATION AND PLUME WIDTH IN NORTH PLATTE RIVER (SCENARIO 1) UNDER HIGH FLOW FOR COMPLETE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Hours Depth-Mean Coal Concentration along Channel Centerline (mg/l)					
	1	2	3	5	7	9
50	--	--	--	9.78E4	4.03E4	3310
100	--	--	--	6.91E4	2.85E4	2340
200	--	--	1.78E5	4.89E4	2.02E4	1650
300	--	--	1.45E5	3.99E4	1.65E4	1350
400	--	1.93E5	1.26E5	3.46E4	1.43E4	1170
500	--	1.73E5	1.12E5	3.09E4	1.27E4	1050
1,000	--	1.22E5	7.95E4	2.19E4	9010	740
2,000	1.70E5	8.65E4	5.62E4	1.55E4	6370	523
3,000	1.39E5	7.06E4	4.59E4	1.26E4	5200	437
4,000	1.20E5	6.12E4	3.97E4	1.09E4	4510	370
5,000	1.08E5	5.47E4	3.55E4	9780	4030	331
10,000	7.61E4	3.87E4	2.51E4	6910	2850	234

Note: Values are not given for the near field (1st several hours near spill) because model is a far field model and tends to overpredict concentrations in the near field.

TABLE 4-7

PREDICTED COAL CONCENTRATION AND PLUME WIDTH IN NORTH PLATTE RIVER (SCENARIO 1) UNDER HIGH FLOW FOR ORIFICE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Hours Depth-Mean Coal Concentration along Channel Centerline (mg/l)									
	1	2	3	5	7	10	14	18	22	24
50	23,000	36,000	49,600	78,400	102,800	151,000	60,300	38,800	6,260	2,650
100	16,300	25,400	35,100	55,400	72,700	107,000	42,700	27,400	4,420	1,870
200	11,500	18,000	24,800	39,200	51,400	75,600	30,200	19,400	3,130	1,320
300	9,400	14,700	20,300	32,000	42,000	61,700	24,600	15,800	2,550	1,080
400	8,150	12,700	17,500	27,700	36,400	53,400	21,300	13,700	2,210	936
500	7,290	11,400	15,700	24,800	32,500	47,800	19,100	12,300	1,980	837
1,000	5,150	8,040	11,100	17,500	23,000	33,800	13,500	8,680	1,400	592
2,000	3,640	5,690	7,850	12,400	16,300	23,900	9,540	6,140	989	419
3,000	2,970	4,640	6,410	10,100	13,300	19,500	7,790	5,010	808	342
4,000	2,580	4,020	5,550	8,760	11,500	16,900	6,750	4,340	700	296
5,000	2,300	3,600	4,960	7,830	10,300	15,100	6,030	3,880	626	265
10,000	1,630	2,540	3,510	5,540	7,270	10,700	4,270	2,740	442	187

Plume Dimensions	
Dist.(ft)	Width(ft)
50	9.1
100	12.9
150	15.8
200	18.2
300	23.2

TABLE 4-8

PREDICTED COAL CONCENTRATION IN SAND CREEK (SCENARIO 2) UNDER HIGH FLOW FOR ORIFICE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Hours Depth-Mean Coal Concentration along Channel Centerline (mg/l)						
	1	2	5	11	16	20	23
50	52,600	54,500	43,500	35,600	10,600	4,920	757
100	37,200	38,500	30,800	25,200	7,490	3,480	535
200	26,300	27,300	21,800	17,800	5,300	2,460	378
300	21,500	22,300	17,800	14,500	4,230	2,010	307
400	18,600	19,300	15,400	12,600	3,750	1,740	268
500	16,600	17,200	13,800	11,300	3,350	1,560	239
1,000	11,800	12,200	9,730	7,960	2,370	1,100	169
2,000	8,320	8,620	6,880	5,630	1,680	778	120
3,000	6,790	7,040	5,620	4,590	1,370	635	98
4,000	5,880	6,090	4,870	3,980	1,180	550	85
5,000	5,260	5,450	4,350	3,560	1,060	492	76
10,000	3,720	3,850	3,080	2,520	749	348	53
14,300	3,110	3,230	2,580	2,110	627	292	45

TABLE 4-9

PREDICTED COAL CONCENTRATION AND PLUME WIDTH IN ILLINOIS RIVER (SCENARIO 4) UNDER HIGH FLOW FOR COMPLETE RUPTURE SPILL

Distance Downstream from Point of Spill	Minutes Depth-Mean Coal Concentration along Channel Centerline (mg/l)				
(ft)	5	10	20	30	40
50	27,900	22,400	11,400	6,730	3,140
100	19,800	15,800	8,040	4,760	2,220
200	14,000	11,200	5,680	3,360	1,570
300	11,400	9,120	4,640	2,750	1,280
400	9,880	7,900	4,020	2,380	1,110
500	8,830	7,070	3,600	2,130	992
1,000	6,250	5,000	2,540	1,500	701
2,000	4,420	3,530	1,800	1,060	496
3,000	3,606	2,890	1,470	869	405
4,000	3,120	2,500	1,270	752	351
5,000	2,790	2,240	1,140	673	314
10,000	1,980	1,580	804	476	222
99,000	628	502	256	151	70

Plume Dimensions

Dist. (ft)	Width(ft)
50	15.4
100	21.8
150	26.7
200	30.8

TABLE 4-10

PREDICTED COAL CONCENTRATION AND PLUME WIDTH IN ILLINOIS RIVER (SCENARIO 4) UNDER HIGH FLOW FOR ORIFICE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Hours Depth-Mean Coal Concentration along Channel Centerline (mg/l) 1	2	3	4	6	8	10	12	15
50	2,830	2,190	2,280	2,510	1,360	1,270	702	587	86
100	2,000	1,550	1,610	1,770	961	901	496	415	61
200	1,420	1,100	1,140	1,252	680	637	351	294	43
300	1,160	894	929	1,020	555	520	286	240	35
400	1,000	774	804	886	481	451	248	208	30
500	896	693	719	792	430	402	222	186	27
1,000	634	490	509	560	304	284	157	131	19
2,000	448	346	360	396	215	201	111	93	14
3,000	367	282	294	323	176	165	91	76	11
4,000	317	244	255	280	152	142	78	66	10
5,000	283	219	228	250	136	127	70	59	8
10,000	200	154	161	177	96	90	50	42	6
990,000	64	49	51	56	31	29	16	9	2

Plume Dimensions

Dist.(ft)	Width(ft)
50	15.4
100	21.8
150	26.7
200	30.8

TABLE 4-11

PREDICTED COAL CONCENTRATION, PLUME WIDTH, AND SETTLING IN ILLINOIS RIVER (SCENARIO 4) UNDER LOW FLOW FOR ORIFICE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Hours Depth-Mean Coal Concentration along Channel Centerline (mg/l)						
	1	2	4	6	9	12	15
50	1.99E5	1.54E5	1.76E5	9.54E4	7.63E4	4.12E4	6,020
100	1.41E5	1.09E5	1.24E5	6.74E4	5.40E4	2.91E4	4,260
200	9.94E4	7.68E4	8.79E4	4.77E4	3.82E4	2.06E4	3,010
300	8.12E4	6.27E4	7.17E4	3.89E4	3.12E4	1.68E4	2,460
400	7.03E4	5.43E4	6.21E4	3.37E4	2.70E4	1.46E4	2,130
500	6.29E4	4.86E4	5.56E4	3.02E4	2.41E4	1.30E4	1,910
1,000	4.45E4	3.44E4	3.93E4	2.13E4	1.71E4	9,210	1,350
2,000	3.14E4	2.43E4	2.78E4	1.51E4	1.21E4	6,510	953
3,000	2.57E4	1.98E4	2.28E4	1.23E4	9,850	5,310	778
4,000	2.22E4	1.72E4	1.96E4	1.07E4	8,530	4,600	674
5,000	1.99E4	1.53E4	1.76E4	9,540	7,630	4,120	602
10,000	1.41E4	1.09E4	1.24E4	6,740	5,400	2,910	426
43,600	6,730	5,200	5,950	3,230	2,580	1,390	204

Characteristics of Saturated Settled Coal

Dist. (ft)	Plume Width (ft)	Cum. Area (ft^2)	Cum. % Settled	Cum. Vol. (ft^3)	Average Thickness (in.)
25	4.3	65	1.5	490	8.1
37.5	5.3	125	1.5	492	0.4

TABLE 4-12

PREDICTED COAL CONCENTRATION, PLUME WIDTH AND SETTLING IN SALINE RIVER (SCENARIO 6) UNDER HIGH FLOW FOR COMPLETE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Minutes Depth-Mean Coal Concentration along Channel Centerline (mg/l) 30	60	90	180	270	360
50	23,300	7,620	6,970	4,860	2,110	176
100	16,200	5,310	4,860	3,390	1,470	122
200	11,400	3,720	3,410	2,380	1,030	86
300	9,270	3,040	2,780	1,940	841	70
400	8,030	2,630	2,410	1,680	728	61
500	7,180	2,350	2,150	1,500	651	54
1,000	5,080	1,660	1,520	1,060	461	38
2,000	3,590	1,180	1,080	750	326	27
3,000	2,930	960	889	613	266	22
4,000	2,540	832	761	531	230	19
5,000	2,270	744	681	475	206	17
10,000	1,610	526	481	336	146	12
868,000	172	56	52	36	16	1

Characteristics of Sasturated Settled Coal

Dist. (ft)	Plume Width (ft)	Cum. Area (ft^2)	Cum. % Settled	Cum. Vol. (ft^3)	Average Thickness (in.)
50	14.4	360	.04	1031	34.4
100	20.3	1228	.05	1448	5.7
150	24.9	2358	.06	1581	1.4
200	28.7	3698	.06	1631	0.45
250	32.1	5218	.06	1647	0.13

TABLE 4-13

PREDICTED COAL CONCENTRATION, PLUME WIDTH, AND SETTLING IN SALINE RIVER (SCENARIO 6) UNDER HIGH FLOW FOR ORIFICE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Hours Depth-Mean Coal Concentration along Channel Centerline (mg/l) 1	2	4	6	8	10	12	14	16	18
50	1410	1290	1230	1170	1050	937	762	645	527	293
100	980	898	857	816	735	653	531	450	367	204
200	687	630	601	573	516	458	372	315	258	143
300	561	514	490	467	420	374	304	257	210	117
400	485	445	426	405	364	324	263	223	182	101
500	434	398	380	362	326	289	235	199	163	90
1,000	307	281	268	256	230	205	166	141	115	64
2,000	217	199	190	181	163	144	118	100	81	45
3,000	177	162	155	148	133	118	96	81	66	37
4,000	154	140	134	128	115	102	83	70	58	32
5,000	137	125	120	114	103	92	74	63	51	29
10,000	97	89	85	81	73	65	53	44	36	20
868,000	7	6	6	6	5	5	4	3	3	1

Characteristics of Saturated Settled Coal

Dist. (ft)	Plume Width (ft)	Cum. Area (ft^2)	Cum. % Settled	Cum. Vol. (ft^3)	Average Thickness (in.)
25	10.2	128	.02	164	15.4
50	14.4	436	.04	264	3.9
75	17.6	836	.05	326	1.9
100	20.3	1309	.05	370	1.1
125	22.7	1847	.05	388	0.4
150	24.9	2567	.06	402	0.2
175	26.9	3215	.06	411	0.2
200	28.7	3910	.06	417	0.1
225	30.5	4650	.06	420	
250	32.1	5432	.06	422	
275	33.7	6255	.06	423	

TABLE 4-14

PREDICTED COAL CONCENTRATION AND PLUME WIDTH IN SALINE RIVER (SCENARIO 6) UNDER LOW FLOW FOR COMPLETE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Minutes Depth-Mean Coal Concentration along Channel Centerline (mg/l) 30	60	120	210	360
50	1.87E5	6.12E4	5.09E4	3.20E4	4710
100	1.32E5	4.33E4	3.60E4	2.26E4	3330
200	9.35E4	3.07E4	2.54E4	1.60E4	2350
300	7.63E4	2.50E4	2.08E4	1.31E4	1920
400	6.61E4	2.16E4	1.80E4	1.13E4	1660
500	5.91E4	1.94E4	1.61E4	1.01E4	1490
1,000	4.18E4	1.37E4	1.14E4	7160	1050
2,000	2.96E4	9680	8040	5060	745
3,000	2.41E4	7900	6570	4130	608
4,000	2.09E4	6840	5690	3580	526
5,000	1.87E4	6120	5090	3200	471
10,000	1.32E4	4330	3600	2260	332
24,400	8406	2770	2300	1450	64

Plume Dimensions

Dist. (ft)	Width(ft)
25	4.5
50	6.3
75	7.8
100	9.0
125	10.0

TABLE 4-15

PREDICTED COAL CONCENTRATION AND PLUME WIDTH IN SALINE RIVER (SCENARIO 6) UNDER LOW FLOW FOR ORIFICE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Hours Depth-Mean Coal Concentration along Channel Centerline (mg/l) 1	2	3	5	8	11	15	19
50	11,300	10,400	10,800	10,400	8,480	6,590	4,710	942
100	7,990	7,330	7,660	7,330	6,000	4,660	3,330	666
200	5,650	5,180	5,420	5,180	4,240	3,300	2,350	471
300	4,610	4,230	4,420	4,230	3,460	2,700	1,920	384
400	4,000	3,660	3,830	3,660	3,000	2,330	1,660	333
500	3,570	3,280	3,421	3,280	2,680	2,080	1,490	298
1,000	2,530	2,320	2,420	2,320	1,900	1,470	1,050	211
2,000	1,790	1,640	1,710	1,640	1,340	1,040	745	149
3,000	1,460	1,340	1,400	1,340	1,094	851	608	122
4,000	1,260	1,160	1,210	1,160	948	737	526	105
5,000	1,130	1,040	1,080	1,040	848	659	471	94
10,000	799	732	766	732	599	466	333	67
24,300	514	471	492	471	385	300	214	43

Plume Dimensions

Dist.(ft)	Width(ft)
25	4.7
50	6.6
75	8.1
100	9.4
125	10.5
150	11.5

TABLE 4-16

PREDICTED COAL CONCENTRATION, PLUME WIDTH, AND SETTLING IN BAYOU COCODRIE (SCENARIO 7) UNDER HIGH FLOW FOR COMPLETE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Depth-Mean Coal Concentration along Channel Centerline (mg/l)				
	Minutes				
	15	30	45	75	105
50	5160	4710	4260	1900	272
100	3370	3080	2780	1240	177
200	2220	2020	1830	818	117
300	1770	1620	1460	653	93
400	1530	1390	1260	562	80
500	1360	1240	1120	502	72
1,000	962	878	793	354	51
2,000	680	621	561	251	36
3,000	555	507	458	205	29
4,000	481	439	397	177	25
5,000	430	392	355	158	23
10,000	304	278	251	112	16
69,700	115	105	95	42	6

Characteristics of Saturated Settled Coal

Dist. (ft)	Plume Width (ft)	Cum. Area (ft^2)	Cum. % Settled	Cum Vol. (ft^3)	Average Thickness (in.)
50	12.7	318	.12	695	26
100	18.0	1,085	.19	1071	5.9
150	22.1	2,088	.23	1274	2.4
200	25.5	3,278	.25	1384	1.1
250	28.5	4,228	.26	1444	0.53
300	31.2	6,120	.26	1476	0.30
350	33.7	7,742	.27	1493	0.13
400	36.1	9,488	.27	1503	0.07
450	38.2	11,345	.27	1507	0.03

TABLE 4-17

PREDICTED COAL CONCENTRATION, PLUME WIDTH, AND SETTLING IN BAYOU COCODRIE (SCENARIO 7) UNDER HIGH FLOW FOR ORIFICE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Depth-Mean Coal Concentration along Channel Centerline (mg/l)				
	Hours				
	1	2	3	4	5
50	4620	2080	1180	815	272
100	3020	1360	769	532	177
200	1990	895	506	350	117
300	1590	715	404	280	93
400	1360	615	348	241	80
500	1220	549	311	215	72
1,000	861	388	219	152	51
2,000	609	274	155	107	36
3,000	497	224	127	87	29
4,000	430	194	110	76	25
5,000	385	174	98	68	23
10,000	272	123	69	48	16
69,700	103	46	26	18	6

Characteristics of Saturated Settled Coal

Dist. (ft)	Plume Width (ft)	Cum. Area (ft^2)	Cum. % Settled	Cum. Vol. (ft^3)	Average Thickness (in.)
50	12.7	318	0.12	303	11.4
100	18.0	1,086	0.19	467	2.6
150	22.1	2,088	0.23	556	1.1
200	25.5	3,278	0.25	604	0.48
250	28.5	4,628	0.26	630	0.23
300	31.2	6,120	0.26	644	0.11
350	33.7	7,742	0.27	651	0.05
400	36.1	9,487	0.27	655	0.03
450	38.2	11,345	0.27	658	0.02

TABLE 4-18

PREDICTED COAL CONCENTRATION, PLUME WIDTH, AND SETTLING IN BAYOU COCODRIE (SCENARIO 7) UNDER LOW FLOW FOR COMPLETE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Depth-Mean Coal Concentration along Channel Centerline (mg/l) Minutes 15	30	45	90	105
50	3.33E4	3.03E4	2.74E4	3500	1750
100	2.35E4	2.14E4	1.93E4	2470	1230
200	1.66E4	1.51E4	1.37E4	1750	873
300	1.35E4	1.24E4	1.12E4	1430	713
400	1.17E4	1.07E4	9670	1230	617
500	1.05E4	9570	8650	1100	552
1000	7420	6770	6120	781	390
2000	5250	4790	4320	552	276
3000	4280	3910	3530	451	225
4000	3710	3380	3060	390	195
5000	3320	3030	2740	349	175
8370	2560	2340	2110	270	135

Characteristics of Settled Saturated Coal

Dist.(ft)	Plume Width (ft)	Cum. Area (ft^2)	Cum. % Settled	Cum. Vol. (ft^3)	Average Thickness (in.)
50	6.6	200	.11	603	6.6
75	8.1	384	.11	615	0.78
100	9.4	602	.11	616	0.05

TABLE 4-19

PREDICTED COAL CONCENTRATION, PLUME WIDTH, AND SETTLING IN BAYOU COCODRIE (SCENARIO 7) UNDER LOW FLOW FOR ORIFICE RUPTURE SPILL

Distance Downstream from Point of Spill (ft)	Depth-Mean Coal Concentration along Channel Centerline (mg/l)				
	Hours				
	1	2	3	4	5
50	29,800	13,400	7,590	5,250	1,750
100	21,000	9,470	5,350	3,700	1,230
200	14,800	6,700	3,780	2,620	873
300	12,100	5,460	3,090	2,140	713
400	10,500	4,730	2,670	1,850	617
500	9,390	4,230	2,390	1,660	552
1,000	6,640	2,990	1,690	1,170	390
2,000	4,690	2,120	1,200	828	276
3,000	3,830	1,730	977	676	225
4,000	3,320	1,500	846	586	195
5,000	2,970	1,340	757	524	175
8,370	2,290	1,030	585	405	135

Characteristics of Settled Saturated Coal

Dist. (ft)	Plume Width (ft)	Cum. Area (ft^2)	Cum. % Settled	Cum. Vol. (ft^3)	Average Thickness (in.)
50	6.6	200	0.11	263	2.9
75	8.1	384	0.11	268	0.3
100	9.4	603			

The concentrations are relatively high for several cases in this scenario. The reasons are the following: For the low streamflow/complete rupture case the initial spill rate is about equal to the streamflow, so dilution is limited. In the case of low streamflow/orifice rupture, the low depth and low estimated lateral dispersion combined with a relatively high spill rate for an orifice rupture cause the higher predicted concentrations. The relatively high initial spill rate combined with limited lateral diffusion cause high initial concentrations for the high streamflow/complete rupture case.

Tables 4-6 and 4-7 show the concentration versus distance and time for the high flow cases. For the high streamflow/complete rupture case, the concentrations on the order of 10^5 do not persist beyond about five hours after the spill begins.

No settling is predicted for this scenario because of the relatively high stream velocities (see Table 4-5) under both streamflow conditions. The implication of these velocities is that the river is sufficiently turbulent to maintain most of the coal particles in suspension.

Scenario 2 - Sand Creek. As in the previous scenario the concentrations are relatively high for both low streamflow conditions and for the complete rupture spill during the high flow condition. For the low streamflow conditions, the spill rates are much larger than the streamflow and dilution is either negligible (complete rupture case) or very low (orifice rupture). In the high streamflow/complete rupture case the initial spill rate is about equal to the streamflow, as again dilution is limited. Table 4-8 shows the concentrations downstream for the high streamflow orifice rupture case.

A settling of 4 percent of the total spilled volume is predicted for the low streamflow/orifice rupture case. The volume of the settled material would be about 1600 ft^3. The combined effects of low streamflow velocity and a narrow channel may cause quite high levels of saturated coal deposits near the spill. For example, if the channel width is on the order of 10 feet and if the major area of deposition is limited to less than 100 feet downstream of the spill, the average depth of accumulation is 1.6 feet, which is greater than the water depth.

Deviations from this average are likely to be substantial, with higher values near the spill.

Scenario 4 - Illinois River. High concentrations for this scenario are limited to the low streamflow/complete rupture case where the spill rates are about equal to the streamflow. However, the duration of this spill is only 40 minutes.

Settling is estimated to occur for both low streamflow cases. For the orifice rupture it is estimated that 1.5 percent of the total spilled volume will settle. It appears that such settling will occur within 100 feet of the spill site. The average depth and area of the deposit is estimated to be about 1 inch and 9000 ft^2, respectively. For the complete rupture the depth and area would be less than these. The reason that less material is estimated to settle in the complete rupture case is that the complete rupture induces sufficiently high downstream flows and velocity to inhibit settling.

Scenario 6 - Saline River. The concentrations are relatively low for all cases in this scenario. One reason for this is the relatively low spill rates associated with this location. Settling is estimated at 6 percent for each type of spill under high streamflow conditions. Characteristics of the settling are given in Tables 4-12 and 4-13. The area of settling is about the same for both cases, i.e., about 5000 ft^2 for the complete rupture spill and about 6000 ft^2 for the orifice rupture spill. The maximum depth of accumulation is estimated to be about 30 inches for the complete rupture spill and 15 inches for the orifice type spill.

Scenario 7 - Bayou Cocodrie. As in the previous case, the concentrations for this case are relatively low in comparison to the Scenarios 1, 2, and 4. The reason for this is the low spill volumes. On the other hand, settling is relatively high and is estimated at 22 percent under the two high streamflow cases and 11 percent under the two low streamflow cases. The reason for the relatively high settling is the low currents in the bayou (see Table 4-5), which imply less turbulence to maintain the coal in suspension. Tables 4-16 through 4-19 give detailed settling estimates.

From the high streamflow cases where the settling is estimated at 27 percent of the total spilled, the maximum depth of accumulation is estimated to be 26 inches for the complete rupture spill and 11 inches for the orifice type spill. For the low streamflow cases the corresponding depths are 7 inches and 3 inches, respectively. The areas of deposition are approximately 10,000 ft^2 for the high streamflow cases and 600 ft^2 for the low flow cases.

Summary. A summary of the effects of a coal spill in a river or stream may be divided into effects on water column concentration and effects due to settling of the coal onto the stream or river bed.

Water column concentrations are generally highest for the complete rupture spills under low streamflow conditions. Indeed, for certain scenarios the spill rates are much larger than the streamflow and little dilution is achieved. Under high streamflow the concentrations generally decrease with distance downstream because of transverse mixing. In general the effects on the water column are short-lived, i.e., the duration of effects at any one location is on the order of the duration of the spills, which range from about 1 to 24 hours.

Settling does not occur in most cases because the turbulence in the rivers appears sufficient to maintain the relatively light and fine coal in suspension. When settling does occur it generally is less than 10 percent. However, the total volume spilled may be sufficient to cause a maximum deposition on the order of several feet. In some cases it appears that maximum deposition depths could exceed the water depths and therefore cause major changes in the stream hydraulics, including the possibility of partial damming of the stream. In general, deposition occurs relatively close to the spill and the area affected by major settling appears to be generally on the order of 1000 ft^2. Subsequent streamflow events could redistribute the settled coal by moving it as bedload or resuspending it.

A summary of settling for the various scenarios is given in Table 4-20.

Surface Water - Lakes

Methodology and Assumptions. The lake selected for the scenario was Cedar Bluff Reservoir in Kansas. The reservoir is a relatively large lake having a total

TABLE 4-20

SUMMARY OF PREDICTED SETTLING

Scenario	Stream or River	Streamflow	Spill Type	% Settled (by wt)	Approx. Volume Settled (Saturated coal) (ft^3)	Approx. Distance Downstream Affected by Major Deposit (ft)	Approx. Area of Major Deposit (ft^2)	Approx. Average Depth (in.)
1	N. Platte	High	complete	0				
		High	orifice	0				
		Low	complete	0				
		Low	orifice	0				
2	Sand Cr.	High	complete	0				
		High	orifice	0				
		Low	complete	0				
		Low	orifice	4	1600	100	1600	18
4	Illinois R.	High	complete	0				
		High	orifice	0				
		Low	complete	0.5	900	100	9000	1
		Low	orifice	1.5	500	100	9000	0.7
6	Saline R.	High	complete	6	1700	100	1372	15
		High	orifice	6	400	100	1372	4
		Low	complete	0				
		Low	orifice	0				
7	Bayou Cocodrie	High	complete	27	1500	200	2485	7
		High	orifice	27	700	200	2485	3
		Low	complete	11	600	100	700	10
		Low	orifice	11	300	100	700	5

capacity of 377,000 acre feet which corresponds to a maximum depth of 102 feet. Although the reservoir storage has dropped from 95,000 acre feet at the end of water year 1975-76 to 33,000 acre feet at the end of 1978-79, it is a large lake for the purposes of the spill analysis.

The residence times for the lake were estimated from storage-outflow data and this was compared to characteristic settling times of various particle size ranges of the coal. This comparison permits one to estimate the likelihood of the coal remaining in suspension long enough to be withdrawn through the outlet.

Approximate estimates of the average residence times in Cedar Bluff Reservoir were made assuming the steady-state formula for residence time applied. That formula is

$$T_R = \forall / Q_{thru}$$

where

T_S = residence time (T)
$\forall$ = volume of the reservoir (L^3)
Q_{thru} = through flowrate (L^3/T)

The values of Q_{thru} and $\forall$ were taken from storage outflow data. For the water year 75-76 through 78-79 the estimated residence times were 4, 4, 2, and 23 years.

Results. The characteristic settling times of the coarse and medium fractions (which made up approximately 80 percent of the total by weight) were estimated from the fall velocities and depths to be less than several hours. Since the settling times are much less than residence times, it appears that most if not all of the coal will settle to the bottom of the reservoir and this will occur in a rather short time period. Given the relatively low currents characteristic of reservoirs, the major area of deposition is likely to be limited to near the point where the spill entered the lake.

An order of magnitude estimate of the average initial depth of settled material can be made by assuming that the material is distributed over some portion of the bottom of the reservoir. Current reservoir area is approximately between 5000 and 6000 acres. If we assume that the initial area of major deposition is 10 percent of the total, or about 500 acres, the average depth of settled, saturated coal is about 0.6 inches for the complete rupture and 0.5 inches for the orifice rupture.

Redistribution of the initially settled material may follow in response to various factors such as wind generated shear currents and mixing caused by episodic events such as storms. Some of the coal which initially settled ultimately could be transported such that some of it is withdrawn from the reservoir.

The fate of the fine fraction of the coal (which makes up about 20 percent of the total by weight) is difficult to assess because such material may be advected via a density current to either the bottom of the reservoir or some intermediate depth range.

An order of magnitude estimate of the characteristic depth of the layer might be 10 percent of the total depth or about 5 feet.

The persistence of such a layer could be on the order of weeks or months depending on whether the levels of turbulence in the reservoir are sufficient to maintain the fine coal particles in suspension.

Eventually, the coal particles would either settle to the bottom and/or be advected via a withdrawal layer from the reservoir.

Summary. The results for the one lake scenario are less quantitative than those for the stream and river scenarios because of the complexity associated with the numerous processes affecting the spill. For example, an important factor is the effect of vertical stratification on the possible development, movement, and spreading of a density current created by the spill. Such factors to be evaluated require extensive data over various seasons and more extensive analysis than appears to be warranted here.

Based on the one lake scenario, it appears that the medium and coarse fractions of coal (which make up 80 percent of the total by weight) will settle out in an area near the point of entry of the spill into the lake. This material may migrate through and be redistributed over the lakebed by forcing associated with later episodic or seasonal events, such as storms or spring freshets, for example.

It appears that the fine fractions might stay in suspension and cause a density current which could redistribute the coal either along the bottom or through some relatively narrow depth range if the lake is stratified.

In general, if the reservoir were large as in the scenario, most of the coal would eventually settle to the bottom of the lake and contribute to the permanent sediment structure.

Ground Water

Methodology. Predictions of the quantity and quality of slurry water that will reach a ground-water system in the event of a spill involve a detailed analysis of many variables concerning the near-surface geology and hydrology. However, the length of the pipeline and absence of sufficient data necessitated the use of a generalized, conceptual approach rather than a model geared to specific spill scenario assessments as used elsewhere in this report.

An analysis of the proposed pipeline routes was conducted to determine the major aquifers. Then the effects of a pipeline spill were modeled qualitatively to determine which of these aquifers would be most susceptible to contamination in a spill situation.

Alluvial valley sand and gravel aquifers were determined to be the most susceptible to contamination. This type of aquifer is generally most susceptible to contamination from a spill because: (1) coarse grained materials allow rapid infiltration; (2) adsorption, absorption, cation exchange, and precipitation reactions can be minimal; and (3) water supply wells are common in alluvial aquifers.

The proposed pipeline routes will cross many alluvial valley aquifers, and to determine possible impacts on water quality in an alluvial valley a quantitative analysis was made of the spread of contamination away from a rupture in a hypothetical alluvial valley aquifer. The hypothetical model was based in part on the alluvial valley of Beaver Creek, a tributary of the South Platte River near Brush, Colorado, near milepost 283 on the Colorado alternative route. The spread of coal slurry waters from the hypothetical spill site was simulated with the two-dimensional ground-water transport computer code developed by Konikow and Brodehoeft (1978).

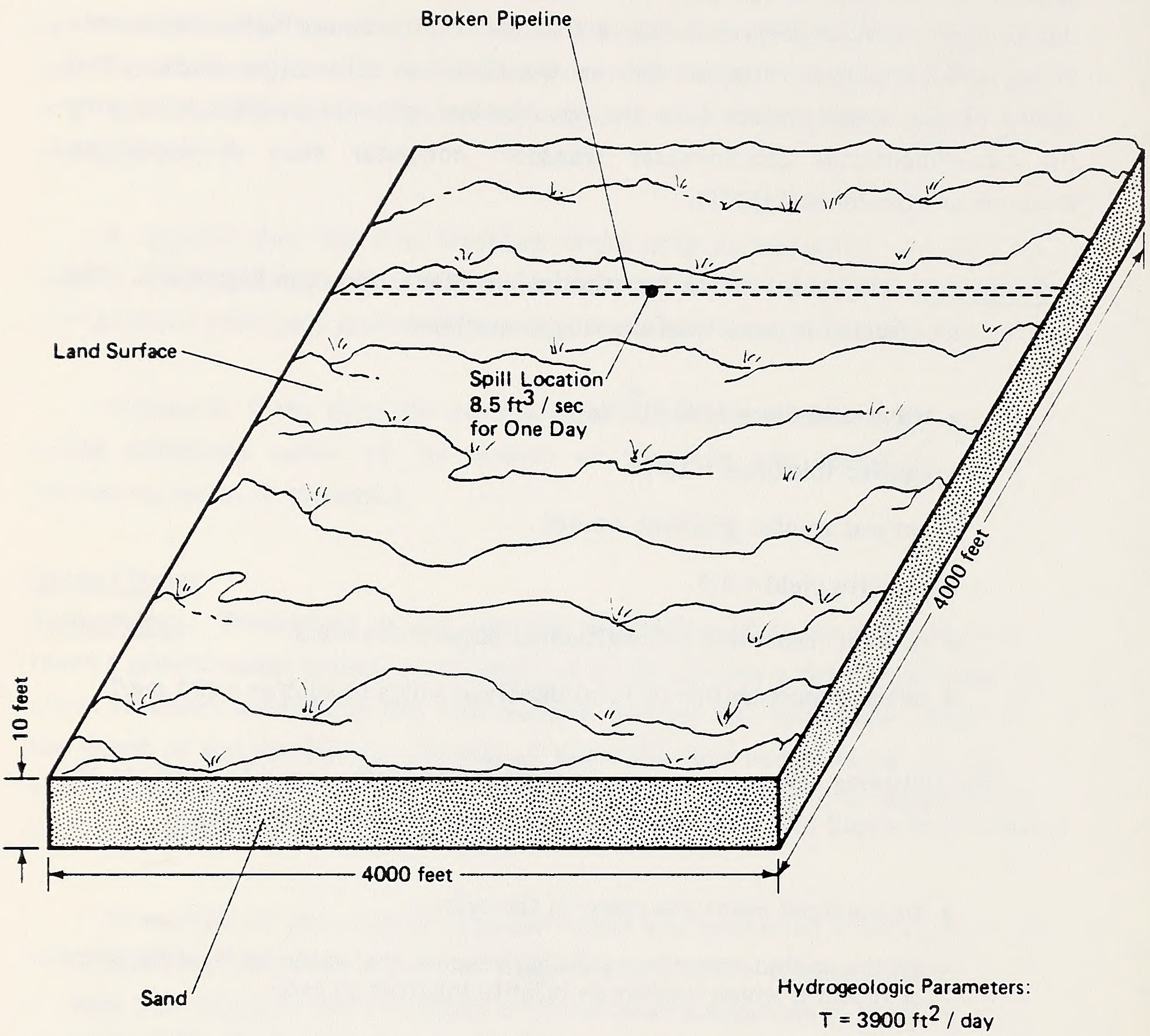
Assumptions. The model of the hypothetical aquifer is shown in Figure 4-8. The aquifer was assumed to have the following properties:

- transmissivity = 3900 ft^2/day
- aquifer thickness = 10 ft
- natural aquifer gradient = 0.008
- specific yield = 0.2
- ratio of transverse to longitudinal dispersivity = 0.3
- initial concentration of total dissolved solids in aquifer = 130 mg/l

The following assumptions were implicit in the method used to simulate the movement of a spill of 8.5 cfs into and through the ground-water system:

- no chemical reactions occur in the system
- all the spilled water immediately reaches the water table at the point of rupture, which implies an infinite infiltration rate
- chemical concentrations are uniform with depth in the aquifer

Results. The simulated spread of the plume of coal slurry water away from the pipeline rupture location is shown in Figures 4-9 and 4-10. The plume of slurry water initially moves rapidly away from the site of the spill. After 100 days, the ground-water influenced by the spill remains within 3000 feet of the spill site. In an actual situation, aquifer thickness is likely to be greater, the infiltration site will not be infinite, the hydraulic conductivity will likely be less, and chemical reactions in the unsaturated zone will be important. As a result, the spread of



Hydrogeologic Parameters:

$T = 3900\ \mathrm{ft}^2 / \mathrm{day}$

$b = 10\ \mathrm{ft}$

$i = 0.008$

$S = 0.2$

$\alpha_T / \alpha_L = 0.3$

$C_0 = 130\ \mathrm{mg}/\ell$

Figure 4-8. CONCEPTUAL HYDROGEOLOGIC MODEL OF PIPELINE SPILL SITE

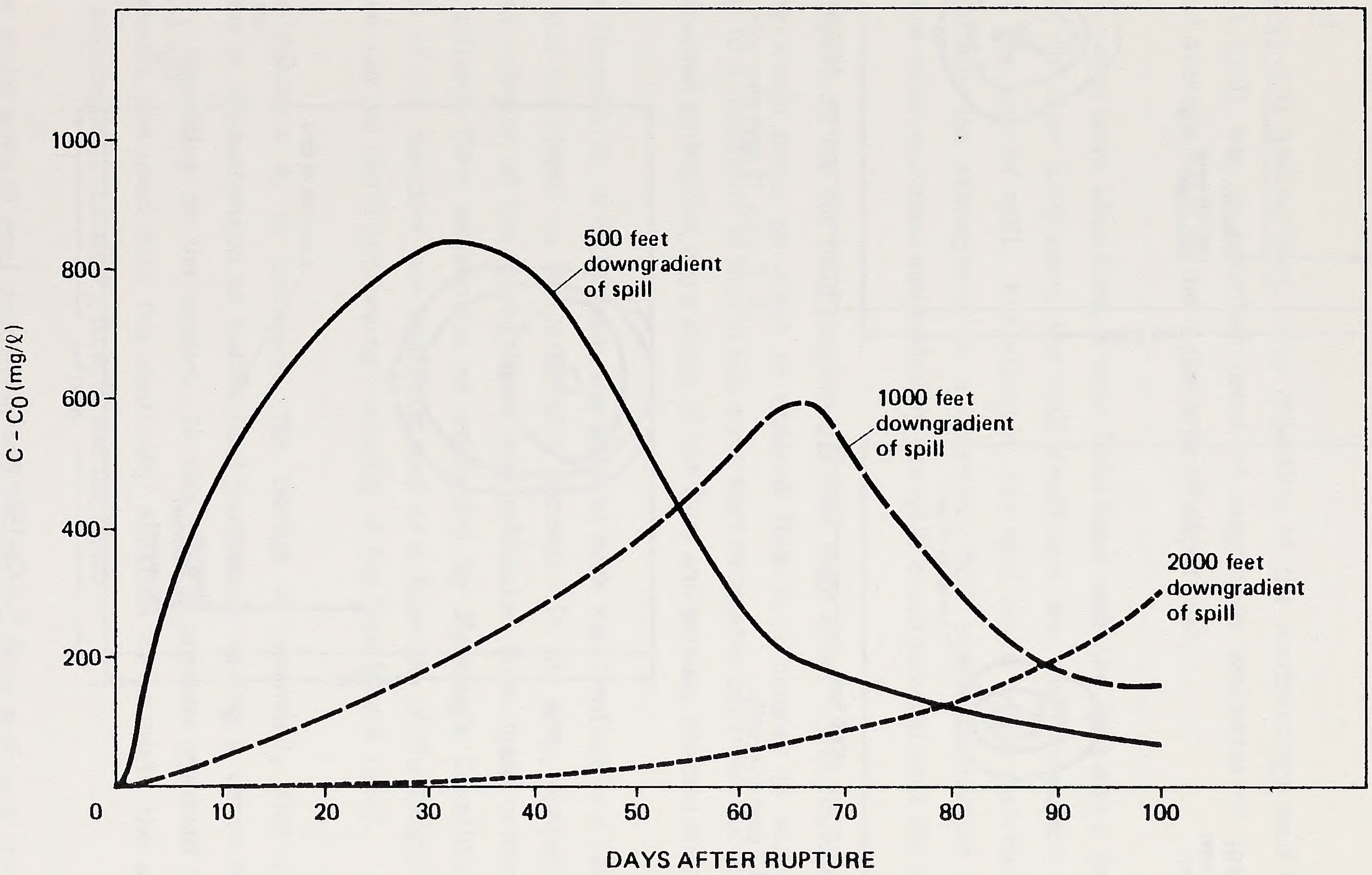
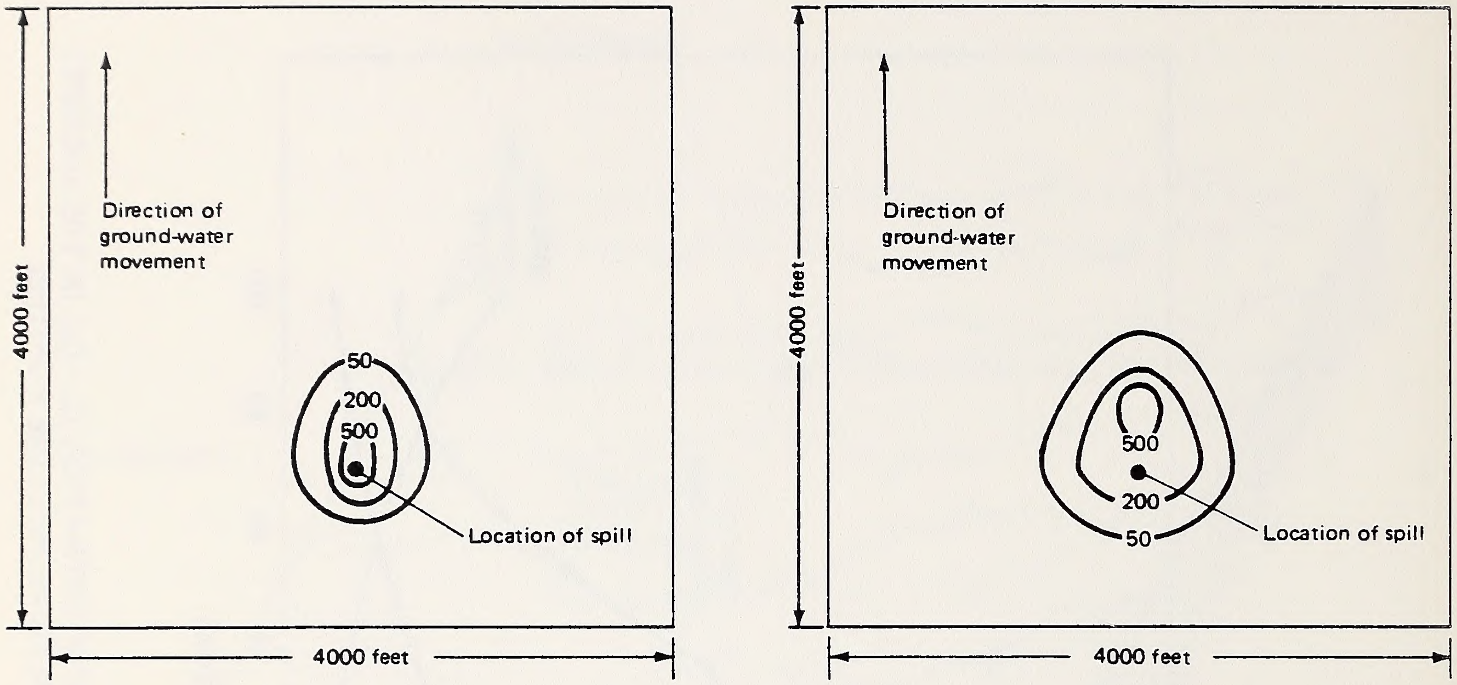
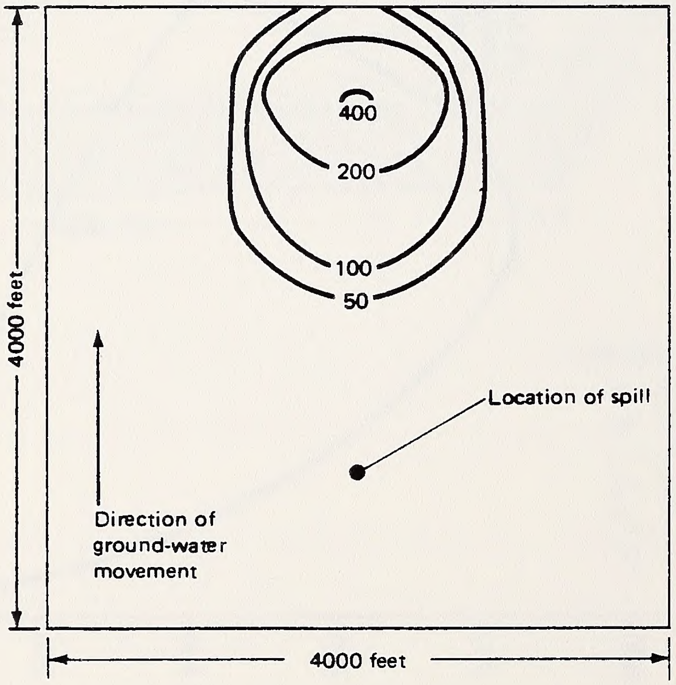


Figure 4-9. CHANGE IN CONCENTRATION ($C - C_0$) IN THE VICINITY OF A HYPOTHETICAL PIPELINE RUPTURE



1. C – C_0 2.7 days after spill.

2. C – C_0 12 days after spill.



C = Concentration of total dissolved solids at end of specified period.

C_0 = Initial concentration of total dissolved solids in the aquifer.

3. C – C_0 115 days after spill.

Figure 4-10. CHANGE IN CONCENTRATION (C – C_0) AT 2.7, 12, AND 115 DAYS AFTER SPILL

the contaminated plume will be much slower and may never extend out 3000 feet in the aquifer from the rupture site.

Terrestrial

Methodology and Assumptions. The objective of the methodology used for the terrestrial spills was to establish order of magnitude estimates of the areal extent and average depth of the major area of deposition.

Two zones were identified, a near field zone near the spill and a far field zone. In the near field zone, the spill conditions are very dependent on the details of the type of spill. For example, the spill could cause material to be discharged into the atmosphere, or a turbulent "boil" region (consisting of coal and perhaps other sediment suspended by the spill) could develop near the spill.

However, in the far field (beyond the near field zone) it was reasoned that the slurry would move by sheet or channel flow in a manner in some ways analagous to a mudflow. It was in this zone that estimates based on the principle of open channel hydraulics were made of the flow and settling characteristics.

For Scenario 3, in Oklahoma, the general area was typified by a tall grass meadow and had slopes on the order of 1 percent. In the area, characteristic depth and velocity of the slurry flows was estimated from mass conservation using a uniform flow assumption as expressed by Manning's Equation. The roughness of the meadow was characterized as a function of the height of the vegetation and the depth and average velocity of the flow (Chow 1959).

For Scenario 8, in Louisiana, the terrain is essentially flat and the vegetation is characterized as bottomland hardwoods having a dense or light understory depending on the season. In this case a pressure gradient - shear force balance was used with the continuity equation to estimate the average velocity and depth of the slurry flow in the far field.

The major area of coal deposition was estimated using a simple trajectory analysis based on the mean flow of the spill and characteristic fall velocities of the coal particles.

Results. For Scenario 3, the depths and average velocity of the slurry flows were estimated for two grass lengths (high, 30 inches and, medium, between 11 and 24 inches), two spill conditions (complete rupture and orifice type rupture), and two assumed widths of flow (100 feet, a somewhat channelized flow, and 1000 feet, a sheet flow).

In general, the combination of low slopes and tall grass, which is highly resistive to flow, caused low average velocity and depths. For example, for the complete rupture spills and a width of 100 feet, the average velocity was approximately 0.3 feet per second for the tall grass condition and 0.9 feet per second for the medium grass length condition. The average depths corresponded to 1.3 and 0.5 for tall and medium grass lengths respectively. (The taller the grass, the lower the velocity and the greater the depth.)

For the orifice rupture case, the average spill rate was sufficiently low that the velocity and depths were decreased to the point that the flow was quasi-laminar.

In both the complete rupture and orifice rupture cases, the velocities of flow were such that deposition of the coarse and medium fractions of coal (these fractions make up 80 percent of the total by weight) were estimated to settle out in less than 1000 feet from the point of the spill. The average depth of settled saturated coal would be about 2 to 3 feet. Deviations from the average could be substantial.

The fine fraction of coal could be transported with the water contained in the spill and eventually be deposited at distances greater than 1000 feet from the spill. The distance that the water would travel would depend on such factors as: whether the flow would become channelized by the the topography, depletion of the flow by infiltration, local impoundment of the spill by natural topographic features or by settling of the coal, and possible interception of the spill by a nearby stream or lake.

For Scenario 8, in Louisiana, estimates of flow and depth were made for both spill types (complete rupture and orifice rupture); however, the difference between the average flows for each of these was relatively small. For a width of 100 feet, light undergrowth corresponds to a Manning's roughness factor n of 0.04 and dense undergrowth has a factor of 0.15. For example, for the light undergrowth and complete rupture spill, and at a distance of 50 feet from the spill, the depth of flow was approximately 0.1 foot and the velocity approximately 0.1 foot per second. This indicates that the flow may be quasi-laminar.

Given these low flow velocities and the flat terrain, the major area of accumulation of settled coal would likely be relatively small (on the order of several acres) and limited to an area near the spill site. The depth of accumulation could be as large as 5 to 10 feet.

The finer coal particles would be advected with the water beyond the major area of deposition. However, given the flat terrain, it appears likely that local ponding of the spill is a possibility.

Summary. The terrestrial spills occurred on relatively flat terrain with extensive vegetative cover, both factors which would tend to decrease the velocity and increase the depth of the slurry flow. In the absence of channelization, it appeared that deposition of most of the coal would occur near the spill, perhaps within a radius on the order of 1000 feet from the spill site. The average depth of such deposition was estimated at less than 1 inch, however, substantial deviations from the average might be expected.

4.B.3 WATER QUALITY IMPACTS

Surface Water

Methodology. To assess surface water quality alteration at the six aquatic spill sites, estimated background water quality conditions have been developed for high and low flow conditions. Based upon the results of the spill dispersion analysis (Section 4.B.2) dilution factors have been applied at each site to estimate receiving water quality for conservative (nonreactive) pollutants that have been shown to leach into the carrier water, including total dissolved solids and sulfates. Biochemical oxygen demand, a nonconservative pollutant, has been evaluated for a one-day spill duration with resultant (postspill) instream levels of dissolved oxygen estimated. Maximum temperature alteration has been estimated for high and low temperature conditions.

Background Conditions. To generally estimate background, or ambient, water quality at the six sites, U.S. EPA STORET (1970-1978) records have been assembled. In general, the highest reported levels of conservative constituents, such as total dissolved solids or sulfates, occur during low flow conditions. However, as indicated by a preliminary linear regression analysis, flow and water quality are not highly correlated (correlation coefficients of less than 0.4) at the six sites, based on a limited number of water quality records. Therefore, water quality data have been assembled for several flow intervals. At each of these flow ranges, average concentrations of individual parameters have been determined.

Where data are unavailable for the crossing site, nearest upstream or downstream gaging records have been inventoried to estimate ambient background conditions under low and high flow cases. The low and high flow intervals analyzed correspond to the levels evaluated for the hydraulic spill modeling (Section 4.B.2)

Conservative Pollutants. The steady state dilution assuming complete vertical and lateral mixing of the slurry centrate (water fraction) with the background flow is given as:

$$F = \frac{Q}{q}$$

where

F = Dilution factor
Q = Background streamflow (cfs)
q = Maximum hourly rate of slurry discharge (cfs)

If the river channel is wide, the point at which complete vertical and lateral mixing is achieved may be quite large (several miles). Equations for estimating this point are given in Fisher et al. (1979).

At less than complete mix, the dilution factor would be less than this value. Several representative values for dilution factors (and distance downstream) have been developed (Section 4.B.2). Receiving water quality (C_+) can then be calculated, since the dilution factor is described as:

$$F = \frac{Cs - Co}{C_+ - Co}$$

where
F = Dilution Factor
Cs = Concentration in the slurry (mg/l)
Co = Background concentration (mg/l)
C_+ = Concentration in receiving water after mixing (mg/l)

Nonconservative Pollutants. To evaluate the effect of slurry spills on dissolved oxygen (DO) levels in receiving waters, the following equations describe the maximum DO deficit, or Dc.

$$Dc = \frac{Kd}{Ka} (Lo)\, e^{\left(- \frac{Kd\, Xc}{U}\right)}$$

$$Xc = \left[\frac{U}{Ka - Kd}\right] \left[\ln \left(\frac{Ka}{Kd}\right)\right]$$

where

Dc = Maximum oxygen deficit (mg/l)

Lo = BOD concentration at $X = O$ (mg/l)

Kd = Deoxygenation or deaeration coefficient

Ka = Reaeration coefficient

Xc = Distance to maximum deficit (feet)

U = Stream velocity (ft/sec)

By substitution, the maximum deficit can be described as:

$$Dc = Lo\, [\theta]^{\left(\frac{\theta}{1-\theta}\right)}$$

where
$$\theta = \frac{Ka}{Kd}$$

Using data collected for depth and velocity at each site, Ka and Kd are determined from plots of stream depth and velocity.

The initial BOD_5 concentration (Lo) is given by:

$$Lo = \frac{W}{Q} = \frac{q(Cs) + Q\,(Co)}{q + Q}$$

where

q = Rate (per day) of slurry discharge (cfs)

Q = Background streamflow (cfs)

Cs = BOD_5 of slurry centrate (water fraction) (mg/l)

Co = Background BOD_5 (mg/l)

Where no background flow exists, or at extremely low background flows (e.g., 1 or 2 cfs), the flow will essentially be made up of the slurry following a spill. As a worst case (neglecting reaeration), in-stream levels of dissolved oxygen can be estimated as the weighted concentration of the background flow with the slurry water fraction (which would have a dissolved oxygen level of essentially 0).

Temperature. Worst case temperature effects can be estimated by the highest and lowest recorded temperatures for the flow interval under study.

$$T = \frac{q(Ts) + Q\,(To)}{q + Q}$$

where

T = Receiving water temperature (°C)

q = Average rate of slurry discharge over spill duration (cfs)

Q = Background streamflow for highest and lowest recorded temperature (cfs)

To = Background temperature in receiving water (highest and lowest recorded) (°C)

Ts = Estimated slurry temperature (°C)

Results. Tables 4-21 through 4-39 present the results of analyses for the six aquatic sites. Maximum and average spill rates have been estimated on the basis of computer outputs for ruptures and spills analysis that appear as an appendix to this technical report. For each site and spill type, the flow rates of solid and water fractions are presented, along with background water quality conditions for low and high flow cases. Estimated water quality alternation is then presented for each spill type under each flow condition.

TABLE 4-21

SPILL TYPE AND BACKGROUND CONDITIONS FOR SITE 1 (NORTH PLATTE RIVER)

Spill Type:	Complete Rupture	Orifice Rupture
Spill Duration:	570 minutes	1440 minutes
Maximum Spill Rate (cfs):		
Total Slurry Flow Rate	243	40.5
Solids Flow Rate	124	17.3
Water Flow Rate	119	23.0
Average Spill Rate (cfs):		
Total Slurry Flow Rate	66.7	25.6
Solids Flow Rate	28.7	7.1
Water Flow Rate	38.0	18.5
Background Conditions:		
	Low Flow	High Flow
Flow (cfs)	250	11,500
TDS (mg/l)	610	640
SO_4 (mg/l)	185	178
BOD_5 (mg/l)	3.7	1.9
DO (mg/l)	8.8	8.9
Temperature (°C):		
Maximum	28.0	25.5
Minimum	18.0	8.0

TABLE 4-22

RECEIVING WATER QUALITY
SITE 1 (NORTH PLATTE)
LOW FLOW CASE

Conservative Parameters

Spill Type	Elapsed Spill Time (Hr)	Distance (Feet)	Receiving Water Quality TDS(mg/l) Pre-Spill	TDS(mg/l) Post-Spill	SO_4(mg/l) Pre-Spill	SO_4(mg/l) Post-Spill
Complete	1	< 50	610	1300	185	640
Rupture	1	7,000	610	≃ 610	185	≃ 185
Orifice	1	1,000	610	1900	185	1100
Rupture	1	10,000	610	1100	185	520

	Complete Rupture	Orifice Rupture
Dissolved Oxygen		
Maximum DO Deficit (mg/l)	<0.1	<0. 1
Minimum DO Level in Receiving Waters (mg/l)	8.7	8.7
Temperature		
Maximum Increase (°C)	0.0	0.0
Maximum Decrease (°C)	6.1	1.6

TABLE 4-23

RECEIVING WATER QUALITY
SITE 1 (NORTH PLATTE RIVER)
HIGH FLOW CASE

Conservative Parameters

Spill Type	Elapsed Spill Time (Hr)	Distance (Feet)	Receiving Water Quality TDS(mg/l) Pre-Spill	TDS(mg/l) Post-Spill	SO$_4$(mg/l) Pre-Spill	SO$_4$(mg/l) Post-Spill
Complete Rupture	1	500	640	1700	180	950
	1	>10,000	640	880	180	350
	9	50	640	650	180	190
	9	>10,000	640	640	180	180
Orifice Rupture	1	50	640	710	180	230
	1	10,000	640	650	180	180
	9	50	640	650	180	190
	9	10,000	640	640	180	180

	Complete Rupture	Orifice Rupture
Dissolved Oxygen		
Maximum DO Deficit (mg/l)	<0.1	<0.1
Minimum DO Level in Receiving Waters (mg/l)	8.9	8.9
Temperature		
Maximum Increase (°C)	0.0	0.0
Maximum Decrease (°C)	0.0	0.0

TABLE 4-24

SPILL TYPE AND BACKGROUND CONDITIONS FOR SITE 2 (SAND CREEK)

Spill Type:	Orifice Rupture	Complete Rupture
Spill Duration:	1379 Minutes	285 Minutes
Maximum Spill Rate:		
Total Slurry Flow Rate	19.5 cfs	435 cfs
Solids Flow Rate	11 cfs	207 cfs
Water Flow Rate	8.5 cfs	228 cfs
Average Spill Rate:		
Total Slurry Flow Rate	6.3 cfs	31.5 cfs
Solids Flow Rate	0.5 cfs	11.6 cfs
Water Flow Rate	5.8 cfs	19.9 cfs

Background Conditions:

	Low Flow	High Flow
Flow (cfs)	2	320
TDS (mg/l)	360	240
SO_4 (mg/l)	25	19
BOD_5 (mg/l)	2	2
DO (mg/l)	7.5	8.2
Temperature (^oC):		
Maximum	29.5	25.5
Minimum	3.0	1.0

TABLE 4-25

RECEIVING WATER QUALITY
SITE 2 (SAND CREEK)
LOW FLOW CASE

Conservative Parameters

Spill Type	Elapsed Spill Time (Hr)	Distance (Feet)	Receiving Water Quality TDS(mg/l) Pre-Spill	TDS(mg/l) Post-Spill	SO_4(mg/l) Pre-Spill	SO_4(mg/l) Post-Spill
Complete Rupture	1	<50	360	1900	25	1100
Orifice Rupture	1	<50	360	1600	25	850

	Complete Rupture	Orifice Rupture
Dissolved Oxygen		
Minimum DO Level in Receiving Waters (mg/l)	0.7	1.9
Temperature		
Maximum Increase (°C)	12.4	10.2
Maximum Decrease (°C)	13.8	11.3

TABLE 4-26

RECEIVING WATER QUALITY
SITE 2 (SAND CREEK)
HIGH FLOW CASE

Conservative Parameters

Spill Type	Elapsed Spill Time (Hr)	Distance (Feet)	Receiving Water Quality TDS(mg/l) Pre-Spill	TDS(mg/l) Post-Spill	SO_4(mg/l) Pre-Spill	SO_4(mg/l) Post-Spill
Complete Rupture	1	<50	240	1100	19	560
	1	1,400	240	≃240	19	≃19
Orifice Rupture	1	50	240	460	19	160
	1	10,000	240	260	19	25
	23	50	240	240	19	21
	23	10,000	240	240	19	19

	Complete Rupture	Orifice Rupture
Dissolved Oxygen		
Maximum DO Deficit (mg/l)	<0.1	<0.1
Minimum DO Level in Receiving Waters (mg/l)	8.1	8.1
Temperature		
Maximum Increase (°C)	6.1	0.4
Maximum Decrease (°C)	4.1	0.3

TABLE 4-27

SPILL TYPE AND BACKGROUND CONDITIONS FOR SITE 3 (RECREATIONAL AREA)

Spill Type:	Orifice Rupture	Complete Rupture
Spill Duration:	1159 Minutes	93 Minutes
Maximum Spill Rate:		
Total Slurry Flow Rate	7.4 cfs	262 cfs
Solids Flow Rate	0.6 cfs	111 cfs
Water Flow Rate	6.8 cfs	151 cfs
Average Spill Rate:		
Total Slurry Flow Rate	3.5 cfs	45 cfs
Solids Flow Rate	0.2 cfs	16 cfs
Water Flow Rate	3.3 cfs	29 cfs

TABLE 4-28

SPILL TYPE AND BACKGROUND CONDITIONS FOR SITE 4 (ILLINOIS RIVER)

Spill Type:	Orifice Rupture	Complete Rupture
Spill Duration:	935 Minutes	57 Minutes
Maximum Spill Rate:		
Total Slurry Flow Rate	10.5 cfs	333 cfs
Solids Flow Rate	0.8 cfs	159 cfs
Water Flow Rate	9.7 cfs	174 cfs
Average Spill Rate:		
Total Slurry Flow Rate	6.7 cfs	86 cfs
Solids Flow Rate	0.6 cfs	38 cfs
Water Flow Rate	6.1 cfs	48 cfs

Background Conditions:

	Low Flow	High Flow
Flow (cfs)	150	16000
TDS (mg/l)	160	100
SO_4 (mg/l)	13	13
BOD_5 (mg/l)	3	3
DO (mg/l)	7.5	8.1
Temperature (°C):		
Maximum	28.5	22.0
Minimum	15.0	11.0

TABLE 4-29

RECEIVING WATER QUALITY
SITE 4 (ILLINOIS RIVER)
LOW FLOW CASE

Conservative Parameters

Spill Type	Elapsed Spill Time (Hr)	Distance (Feet)	Receiving Water Quality TDS(mg/l) Pre-Spill	TDS(mg/l) Post-Spill	SO_4(mg/l) Pre-Spill	SO_4(mg/l) Post-Spill
Complete	0.67	<50	160	1000	13	560
Rupture	0.67	5,000	160	≃160	13	≃13
Orifice	1	50	160	1000	13	560
Rupture	1	10,000	160	220	13	52
	15	50	160	190	13	29
	15	10,000	160	160	13	14

	Complete Rupture	Orifice Rupture
Dissolved Oxygen		
Maximum DO Deficit (mg/l)	<0.1	<0.1
Minimum DO Level in Receiving Waters (mg/l)	7.4	7.4
Temperature		
Maximum Increase (°C)	0.3	<0.1
Maximum Decrease (°C)	7.0	0.8

TABLE 4-30

RECEIVING WATER QUALITY
SITE 4 (ILLINOIS RIVER)
HIGH FLOW CASE

Conservative Parameters

Spill Type	Elapsed Spill Time (Hr)	Distance (Feet)	Receiving Water Quality TDS(mg/l) Pre-Spill	Post-Spill	SO_4(mg/l) Pre-Spill	Post-Spill
Complete Rupture	0.08	50	100	230	13	91
	0.08	10,000	100	110	13	18
	0.67	50	100	110	13	22
	0.67	10,000	100	100	13	14
Orifice Rupture	1	50	100	110	13	21
	1	10,000	100	100	13	14
	15	50	100	100	13	13
	15	10,000	100	100	13	13

	Complete Rupture	Orifice Rupture
Dissolved Oxygen		
Maximum DO Deficit (mg/l)	<0.1	<0.1
Minimum DO Level in Receiving Waters (mg/l)	8.0	8.0
Temperature		
Maximum Increase (°C)	<0.1	0.1
Maximum Decrease (°C)	<0.1	0.1

TABLE 4-31

SPILL TYPE AND BACKGROUND CONDITIONS FOR SITE 5 (CEDAR BLUFFS RESERVOIR)

Spill Type:	Orifice Rupture	Complete Rupture
Spill Duration:	1440 Minutes	965 Minutes
Maximum Spill Rate:		
Total Slurry Flow Rate	34 cfs	292 cfs
Solids Flow Rate	13 cfs	140 cfs
Water Flow Rate	21 cfs	152 cfs
Average Spill Rate:		
Total Slurry Flow Rate	29 cfs	53 cfs
Solids Flow Rate	9 cfs	25 cfs
Water Flow Rate	20 cfs	28 cfs

Background Conditions:

Reservoir Volume
Maximum 269,400 acre-feet[a]
Minimum 32,620 acre-feet[a]

	Surface	Bottom
DO (mg/l)[b]	6.8	5.9
SO_4 (mg/l)[b]	575	584
BOD_5 (mg/l)[b]	2	2
Total Hardness (mg/l)	609	610
Temperature (°C)		
Maximum	—	26.5
Minimum	—	3.0
TDS[c]	—	1140

Sources:

[a] U.S. Geological Survey 1950-79.

[b] State of Kansas, Department of Health and Environment 1979.

[c] U.S. Geological Survey 1975-79 (for samples taken at dam outlet).

TABLE 4-32

RECEIVING WATER QUALITY
SITE 5 CEDAR BLUFFS RESERVOIR

Maximum Spill Volume	
Orifice Rupture	39.7 acre-feet
0.12% of historical low reservoir volume.	
Complete Rupture	37.2 acre-feet
0.11% of historical low reservoir volume.	
Minimum Dissolved Oxygen	
Zero mg/l in portions of the hypolimnion under density current conditions	
Temperature	
Maximum Increase	10.1°C
Maximum Decrease	13.4°C
Conservative Parameters	
Maximum Concentration	
TDS	1900 mg/l
SO_4	1100 mg/l

TABLE 4-33

SPILL TYPE AND BACKGROUND CONDITIONS FOR SITE 6 (SALINE RIVER)

Spill Type:	Orifice Rupture	Complete Rupture
Spill Duration:	1168 Minutes	401 Minutes
Maximum Spill Rate:		
Total Slurry Flow Rate	2.7 cfs	31 cfs
Solids Flow Rate	0.2 cfs	15 cfs
Water Flow Rate	2.5 cfs	16 cfs
Average Spill Rate:		
Total Slurry Flow Rate	2.1 cfs	6.1 cfs
Solids Flow Rate	0.1 cfs	1.2 cfs
Water Flow Rate	2.0 cfs	4.9 cfs

Background Conditions:

	Low Flow	High Flow
Flow (cfs)	250	11,500
TDS (mg/l)	70	60
SO_4 (mg/l)	16.0	14
BOD_5 (mg/l)	2.0	2.0
DO (mg/l)	7.7	10.0
Temperature (^{o}C):		
Maximum	26.0	28.0
Minimum	7.0	1.0

TABLE 4-34

RECEIVING WATER QUALITY
SITE 6 (SALINE RIVER)
LOW FLOW CASE

Conservative Parameters

Spill Type	Elapsed Spill Time (Hr)	Distance (Feet)	Receiving Water Quality TDS(mg/l) Pre-Spill	Receiving Water Quality TDS(mg/l) Post-Spill	Receiving Water Quality SO_4(mg/l) Pre-Spill	Receiving Water Quality SO_4(mg/l) Post-Spill
Complete Rupture	0.5	50	70	910	16	510
	0.5	10,000	70	130	16	52
	6	50	70	80	16	20
	6	10,000	70	70	16	16
Orifice Rupture	1	50	70	120	16	46
	1	10,000	70	74	16	18
	18	50	70	74	16	19
	18	10,000	70	70	16	16

	Complete Rupture	Orifice Rupture
Dissolved Oxygen		
Maximum DO Deficit (mg/l)	<0.1	<0. 1
Minimum DO Level in Receiving Waters (mg/l)	7.6	7.6
Temperature		
Maximum Increase (°C)	0.5	<0.1
Maximum Decrease (°C)	0.7	0.1

TABLE 4-35

RECEIVING WATER QUALITY
SITE 6 (SALINE RIVER)
HIGH FLOW CASE

Conservative Parameters

Spill Type	Elapsed Spill Time (Hr)	Distance (Feet)	Receiving Water Quality TDS(mg/l) Pre-Spill	TDS(mg/l) Post-Spill	SO_4(mg/l) Pre-Spill	SO_4(mg/l) Post-Spill
Complete Rupture	0.5	50	60	170	14	78
	0.5	10,000	60	68	14	19
	6	50	60	61	14	14
	6	10,000	60	60	14	14
Orifice Rupture	1	50	60	67	14	18
	1	10,000	60	60	14	14
	18	50	60	61	14	14
	18	10,000	60	60	14	14

	Complete Rupture	Orifice Rupture
Dissolved Oxygen		
Maximum DO Deficit (mg/l)	< 0.1	< 0. 1
Minimum DO Level in Receiving Waters (mg/l)	9.9	9.9
Temperature		
Maximum Increase (°C)	<0.1	<0.1
Maximum Decrease (°C)	<0.1	<0.1

TABLE 4-36

SPILL TYPE AND BACKGROUND CONDITIONS FOR SITE 7 (BAYOU COCODRIE)

Spill Type:	Orifice Rupture	Complete Rupture
Spill Duration:	300 Minutes	185 Minutes
Maximum Spill Rate:		
Total Slurry Flow Rate	1.6 cfs	5 cfs
Solids Flow Rate	0.4 cfs	1.6 cfs
Water Flow Rate	1.2 cfs	3.4 cfs
Average Spill Rate:		
Total Slurry Flow Rate	1.2 cfs	2.0 cfs
Solids Flow Rate	0.1 cfs	0.5 cfs
Water Flow Rate	1.1 cfs	1.5 cfs

Background Conditions:

	Low Flow	High Flow
Flow (cfs)	100	1900
TDS (mg/l)	46	34
SO_4 (mg/l)	2.5	4
BOD_5	2.3	3.5
DO (mg/l)	5.0	9.2
Temperature (°C):		
Maximum	28.5	16.0
Minimum	20.5	9.0

TABLE 4-37

RECEIVING WATER QUALITY
SITE 7 (BAYOU COCODRIE)
LOW FLOW CASE

Conservative Parameters

			Receiving Water Quality			
			TDS(mg/l)		SO_4(mg/l)	
Spill Type	Elapsed Spill Time (Hr)	Distance (Feet)	Pre-Spill	Post-Spill	Pre-Spill	Post-Spill
Complete Rupture	0.25	50	46	220	2.5	100
	0.25	10,000	46	63	2.5	13
	1.8	50	46	55	2.5	8
	1.8	10,000	46	47	2.5	3
Orifice Rupture	1	50	46	200	2.5	94
	1	10,000	46	62	2.5	12
	5	50	46	55	2.5	8
	5	10,000	46	47	2.5	3

	Complete Rupture	Orifice Rupture
Dissolved Oxygen		
Maximum DO Deficit (mg/l)	<0.1	< 0. 1
Minimum DO Level in Receiving Waters (mg/l)	4.9	4.9
Temperature		
Maximum Increase (°C)	0	0
Maximum Decrease (°C)	0.3	0.1

TABLE 4-38

RECEIVING WATER QUALITY
SITE 7 (BAYOU COCODRIE)
HIGH FLOW CASE

Conservative Parameters

Spill Type	Elapsed Spill Time (Hr)	Distance (Feet)	Receiving Water Quality TDS(mg/l) Pre-Spill	TDS(mg/l) Post-Spill	SO_4(mg/l) Pre-Spill	SO_4(mg/l) Post-Spill
Complete Rupture	0.25	50	34	62	4	20
	0.25	10,000	34	36	4	5
	1.8	50	34	35	4	5
	1.8	10,000	34	34	4	4
Orifice Rupture	1	50	34	59	4	18
	1	10,000	34	36	4	5
	5	50	34	35	4	5
	5	10,000	34	34	4	4

	Complete Rupture	Orifice Rupture
Dissolved Oxygen		
Maximum DO Deficit (mg/l)	3.2	3.2
Minimum DO Level in Receiving Waters (mg/l)	3-4	3-4
Temperature		
Maximum Increase (°C)	< 0.1	<0.1
Maximum Decrease (°C)	0.0	0.0

TABLE 4-39

SPILL TYPE AND BACKGROUND CONDITIONS FOR SITE 8 (BOTTOMLAND HARDWOODS)

Spill Type:	Orifice Rupture	Complete Rupture
Spill Duration:	1440 Minutes	1440 Minutes
Maximum Spill Rate (cfs):		
Total Slurry Flow Rate	2.1	9.8
Solids Flow Rate	0.1	1.7
Water Flow Rate	2.0	8.1
Average Spill Rate:		
Total Slurry Flow Rate	2.0	3.3
Solids Flow Rate	0.1	0.4
Water Flow Rate	1.9	2.9

Summary. Conclusions reached from this evaluation are as follows. Spills into creeks and streams at extremely low ambient flow (e.g., 2 cfs or less) result in dissolved oxygen (DO) levels being immediately depressed to less than 1 mg/l. Levels of TDS and SO_4 would approach the highest concentrations present in the pipeline (e.g., 1900 and 1100 mg/l, respectively) and would persist downstream indefinitely until diluted with tributary or spring inflow. Spills into small feeder streams, or larger streams and rivers at low flow conditions, would not result in a significant DO depletion, except in the case of bayou waterways where minimum levels of 3 to 4 mg/l could occur. TDS levels could reach 1000 to 1300 mg/l and SO_4 levels could reach 500 to 1000 mg/l at distances greater than 50 feet downstream and would return to near ambient levels generally from 4000 to 10,000 feet downstream. In larger rivers, the effects of spills in altering surface water quality would be minor due to dilution, with return to ambient conditions within up to 10,000 feet downstream. The concentration of certain metals at the immediate spill site (e.g., initial downstream plume) could exceed primary drinking water standards and EPA criteria for toxic pollutants. As shown in Table 2-6, these constituents could include chromium, lead, mercury, selenium, and silver. The constituents have been measured in simulation tests at low or trace concentrations. The concentrations in receiving waters would be further reduced due to dilution as well as formation of insoluble hydrous oxides, co-precipitation with other compounds, and adsorption to suspended materials in the water column. The effect of dilution alone would reduce the levels of these constituents below drinking water standards within approximately 50 feet, in a well mixed low-flowing stream (e.g., Sand Creek), and within approximately 5000 feet in a less well mixed, high-flowing river (e.g., North Platte River) assuming background levels up to 50 percent of drinking water standards. Spills into reservoirs would generate a wide variability in receiving water quality alteration, depending upon reservoir volume and detention time, thermal stratification, spill inflow characteristics, background water quality, and so on. In general, a higher density slurry spill moving along the bottom or within the epilimnion could deplete DO levels to less than 1 mg/l, could result in temperature increases or decreases greater than $10^{o}C$, and could increase TDS and SO_4 levels up to 1900 and 1100 mg/l, respectively. In the case of a reservoir spill, coal could accumulate and remain for some time above existing reservoir sediments. Reducing conditions in the coal sediment layer could potentially result in the release of trace metals in soluble ionic form at the sediment-water interface, altering water quality at this interface.

Ground Water

The impacts on the quality of ground water as a result of the hypothetical spill modeling exercise are described below.

Results. After ten days, the EPA secondary drinking water standards for TDS and SO_4 would not be exceeded at any point in the aquifer, though the secondary standard for manganese may be exceeded in most of the plume if manganese is nonreactive. The manganese concentrations would not be a health problem, but only an esthetic problem. In an aquifer with a smaller gradient or lower hydraulic conductivity, elevated TDS and SO_4 concentrations would persist for potentially much longer periods of time. These high concentrations, however, would be confined to an area very near the point of rupture.

The rate of movement of the slurry water (plume) in the aquifer and the changes in background concentrations are sensitive to the model parameters. Decreasing the gradient on the hydraulic conductivity will result in approximately a linear decrease in the rate of plume movement. An increase in the saturated thickness of the aquifer or increase in porosity will cause approximately a linear decrease in the change in the concentration in the plume.

The possible contamination of ground water by trace metals or dissolved organics may be of more importance than the increase in total dissolved solids. Data on pipeline water quality (Table 4-40) show that concentrations of these compounds will be very low. The movement of these substances in the aquifer would mimic the movement of the TDS plume if it is assumed that no chemical reactions occur. Where chemical reactions do occur, these substances would likely be sorbed by the soil and only small amounts would travel any great distances.

In addition to the hypothetical spill modeling, a simple comparison of ground-water quality along the pipeline route with the estimated quality of slurry water can be used in the identification of possible degradation in water quality that would occur if the ground water were contaminated by slurry waters.

TABLE 4-40

REPRESENTATIVE GROUND WATER QUALITY ALONG THE PIPELINE ROUTE (mg/l)

		Location					
		Alluvium					
Chemical Parameter	Pipeline	S. Platte Valley	Beaver Creek	NW Kansas	Bayou Bartholomew	Ogalla Aquifer, Kansas	Dakota Aquifer, South Dakota
Ca	200	202	23	164	-	38	40
Mg	70	83	7	32	-	15	1
SO_4	1100	852	20	164	-	38	40
Cl	70	-	-	53	10-1500	14	240
TDS	1900	1630	130	643	50-3700	295	1180
Mn	<0.23	-	-	0.4	-	-	0.03
Ni	<0.1	-	-	-	-	-	-
Zn	<0.6	-	-	-	-	-	-
Fe	<0.3	0.02	0.14	0.2	3	0.4	0.26

Sources: Jenkins and Pabst 1975; Bjorklund and Brown 1957; Broom and Reed 1973; and WCC 1981a.

The quality of ground water that can be expected in the principal near-surface aquifers along the pipeline route varies widely and is tabulated in Table 4-40.

The anticipated quality of the coal slurry water in the pipeline, which is characterized by the quality of the source water and the constituents that leach from the coal or are removed by the coal during transport, would meet primary drinking water standards, but would exceed the secondary standards for total dissolved solids (TDS), sulfate, and possibly manganese. This water would be expected to be significantly poorer than the water quality in most aquifers near the pipeline route. The mixing of pipeline water with ground water, assuming no chemical reactions occur, would result in the exceedance of these same secondary standards in the extreme case only.

Summary. In conclusion, the impact of a pipeline rupture on ground-water quality, even in the most sensitive of environments, is not likely to be severe. The plume of contaminated water will not move rapidly away from the vicinity of the spill. If measures are taken soon after the rupture to clean up the spilled water, impacts on the ground-water system should be minimal. Locally, some unacceptable water quality damages may occur if the rupture occurs near a water supply well.

4.B.4 ECOLOGICAL IMPACTS

Six of the eight spill scenarios involve aquatic habitats and two consider terrestrial habitats. For the purposes of these analyses it will be assumed that terrestrial spills would not contaminate local aquatic habitats and, likewise, aquatic spills would be confined to affected water bodies.

Detailed descriptions of the habitats and biota at the various spill locations are included in the Terrestrial Biology Technical Report (WCC 1981b), the Threatened and Endangered Species Technical Report (WCC 1981c), and the Aquatic Biology Technical Report (WCC 1981d).

Aquatic Impacts

In all phases of aquatic impact analysis, emphasis will be placed on fishes, macroinvertebrates, and sensitive classification species. Other components of the freshwater community including phytoplankton, zooplankton, and periphyton will be considered only in the few situations where anticipated impacts could significantly affect their populations. In general, the high and rapid reproductive potential of plankton and periphyton populations should make them resistant to short-term spill impacts.

Aquatic biological impacts associated with spills can be conveniently divided into (1) physicochemical water quality phenomena and (2) coal particle suspension and sedimentation phenomena. Synergistic effects will be addressed only when such effects would be anticipated to cause significant biological impacts.

A generic discussion of spill-related impacts is presented below. More specific impact data related to the individual spill scenario sites will be presented under the various scenario headings.

Water Quality and Quantity. Water quality investigations, to date, have indicated that no detectable concentrations of toxic "priority pollutants" would be anticipated in the slurry water.

Water quality characteristics of major biological concern, then, are limited to sulfate, total dissolved solids (TDS), and dissolved oxygen concentrations in addition to water temperature and spill volume.

The quantity of slurry spilled, in relation to the volume of water in the affected water body would, ultimately, determine the degree of biological damage. In general, the smaller the stream in which a spill occurs, the greater the biological damage to be anticipated.

If a slurry spill represented a significant increase in stream discharge volume (e.g. a doubling of volume, or greater) then the physical biological impacts (chemical effects will be discussed below) would be similar to those covered by local rainstorms. The impacts on affected biota would be involuntary downstream or out-of-stream displacement and "scouring" of the streambed.

The temperature of the slurry within the pipeline could significantly affect ambient stream temperatures at spill sites. A sudden increase or decrease in water temperature could result in a localized fish and invertebrate kill as a result of "heat shocks" (Talmage and Coutant 1978) or "cold shock" (Burton et al. 1979).

Available data indicate that the rate at which water temperature changes determines the severity of impact (Burton et al. 1979; U.S. EPA 1976). A slurry spill could cause a relatively rapid temperature change and, therefore, a conservative temperature criterion should be established for these spill analyses. Heat shock and cold shock studies have generally indicated that fish mortality declines as temperature change (ΔT) is limited to approximately 3°C or less. It will be assumed, therefore, that temperature changes of less than 3°C would have no significant impact on aquatic communities. It should be noted that water temperature alterations due to slurry spills would be expected to last for fewer than 24 hours.

The U.S. Environmental Protection Agency (1976) has established a general dissolved oxygen minimum concentration criterion of 5.0 mg/l and, for the purposes of these spill analyses, this criterion will be used to establish levels of biological impact.

Maximum TDS and sulfate concentrations in the slurry water are anticipated to be approximately 1900 and 1100 mg/l, respectively. While these levels are in excess of the suggested domestic water supply concentrations of 250 mg/l (U.S. EPA 1976), it has been demonstrated that common freshwater fishes survived concentrations as high as 10,000 and 15,000 mg/l (U.S. EPA 1976). It is anticipated, therefore, that short-term exposure to 1900 and 1100 mg/l TDS and sulfate concentrations (undiluted) would not have a significant impact on affected aquatic communities.

Suspended Solids And Sedimentation. The approximate suspended solids concentration of the coal slurry would be 400,000 mg/l and, for these analyses, it is assumed that essentially all of the suspended material would be coarse, medium and fine particulate coal. The potential physical biological damage associated with such a dense slurry mixture is, undoubtedly, the major aquatic biological spill issue.

Although general turbidity, suspended solids, and sedimentation data are abundant in the available literature, few published data are available specifically regarding the impacts of coal particles on aquatic biota (Scullion and Edwards 1980). Impact analysis, therefore, will rely on the application of generalized sedimentation and turbidity data. Cordone and Kelley (1961) and Stern and Stickle 1978) have completed extensive reviews of the literature regarding the biological effects of increased sedimentation and turbidity. It has been found that elevated turbidity levels can affect productivity throughout all trophic levels (Karr and Schlosser 1978; Stern and Stickle 1978; Peters 1967; Cordone and Kelley 1961; Gangmark and Bakkala 1960; and many others).

Although sustained periods of exposure to high suspended solids under laboratory conditions have been shown to cause adult and juvenile fish mortality (Herbert and Merkens 1961; Herbert and Richards 1963; and several studies reported in Stern and Stickle 1978), increases in ventilation (Horkel and Pearson 1966), physical damage to gills and other exposed tissues (Herbert and Merkens 1961; Ellis 1944 in Cordone and Kelley 1961), plus other behavioral effects, it has been shown that under natural conditions (Peters 1967; Herbert et al. 1961; Burnside 1967) fish do not remain in areas of high turbidity. These data suggest that the likely response of affected adult and juvenile fishes to increased turbidity would be temporary emigration from the affected area and this sort of response has been documented in the literature (Gammon 1970).

The U.S. Environmental Protection Agency (1976) suggested a suspended solids criterion which ". . .should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life."

Clearly, a site-specific criterion of this sort has more realistic applicability to continuous discharges than to transient (less than 24-hour) spill conditions.

A more realistic criterion for the purposes of coal slurry spill analyses should be related to potential fish mortality. Data cited or published by Wallen (1958) and Hocutt et al. (1976) indicate that there is no evidence of gill clogging or damage in fishes exposed to short-term suspended solids concentrations of approximately 70,000 mg/l. Behavioral effects on fishes (primarily avoidance) have been reported as a result of concentrations as low as 20,000 mg/l. For the purposes of these analyses, avoidance behavior will not be considered a significant fisheries impact since repopulation of the affected habitat would be anticipated after pipeline repair. Avoidance behavior is, in fact, a desirable response under spill conditions.

The suspended solids concentration below which adult and juvenile fish mortality would not be expected to occur is considered to be 70,000 mg/l. Significant impacts on the indigenous invertebrate population, however, would be anticipated to occur at much lower concentrations of approximately 400 mg/l (U.S. EPA 1976) and these will be discussed below.

The most notable fisheries impact anticipated to be associated with spill-induced turbidity would be a potential reduction in reproductive success. When fine sediment settles on coarse unconsolidated substrates the permeability of those substrates is decreased. When eggs are laid in affected areas water may not flow freely over the eggs which can result in a decrease in hatching success (Meehan and Swanston 1977; Auld and Schubel 1978). Auld and Schubel (1978) found that varying amounts of suspended sediments affected the hatching success of species of fish differently. Less than 1000 mg/l did not affect the hatching success of yellow perch, blueback herring, alewife or American shad eggs, but 1000 mg/l significantly reduced the hatching success of white perch and striped bass.

It is also believed that sediment affects the flow of water through gravel, preventing the removal of metabolic waste and entrance of oxygen (Cooper 1965;

Sheridan and McNeil 1968; Meehan and Swanston 1977; and others). Shelton and Pollock (1966) found that if 15 to 30 percent of the interstices in gravel were filled with sediment, there resulted an 85 percent mortality of salmon eggs. The sediment may act as a physical barrier to the fry, even if they do hatch successfully. Sedimentation can also disrupt reproduction by covering spawning grounds (Karr and Schlosser 1978), making them unavailable for reproduction. If a spill were to occur during the spawning period in a nursery area, locally significant impacts on eggs and larval fishes would be anticipated.

If a spill were to coincide with fish migration periods there is a possibility that a spill would interfere with pre- or post-reproductive migration. Such interference has been reported in the literature (U.S. EPA 1976) and the severity of the impact would depend upon the spawning behavior of the species involved, the suspended solids increase anticipated, and the delineation of the downstream area to be affected.

Since most fishes migrate over a period of several days or weeks (Geen et al. 1966) it is anticipated that migration would only be temporarily suspended, and could be expected to resume shortly after the spill ended and ambient suspended solids concentrations returned to normal.

In order for migration or reproductive success to be significantly affected a spill would have to occur during spawning periods at spawning areas. If these conditions were met then some degree of biological damage would be anticipated. It is not possible, however, to quantify the damage since numerous variables exist and current site-specific data are not available.

The primary impacts of stream siltation on aquatic invertebrates would be gill membrane abrasion, smothering, and/or loss of acceptable substrate habitat as a result of substrate in-filling. Casey (1959 as reported in Cordone and Kelley 1961) found that siltation for about 1/4 mile downstream from a dredging operation eliminated macroinvertebrates. There was a 50 percent reduction in numerical abundance one mile below the dredge. Not only do macroinvertebrate populations decrease when sedimentation increases (Tebo 1955), low level sedimentation can alter species composition (Conlan and Ellis 1979; Rosenberg and Wiens 1978). Conlan and Ellis (1979) found that a one cm layer of wood waste resulted in a reduction in biomass and the loss of the majority of suspension feeders with the affected area becoming dominated by deposit feeders. Rosenberg and Wiens (1978) noticed that sediment additions resulted in different drift rates for various invertebrates. White and Gammon (1977) reported that increases in suspended solids to concentrations of less than 100 mg/l resulted in increased drift rates to more than double the normal rate. Since an increase in sedimentation results in a decrease in habitat diversity by filling in the substrate interstices, macroinvertebrate standing crop has been found to decrease (Williams and Mundie 1978; Allan 1975; Barber and Kevern 1973).

Mollusks, in addition to insects, may also be adversely affected by stream siltation. Ellis (1936) reported a general increase in mortality of mussels affected by silt, and many species of snails and mussels specifically avoid silt-substrate areas (Pennak 1978).

While suspended solids concentrations as low as approximately 100 mg/l would be anticipated to stimulate some aquatic insect emigration from the affected area in the form of invertebrate drift (White and Gammon 1977), deposition of as little as approximately 0.3 inches of coal particles would be expected to significantly reduce invertebrate production in the affected area.

Data summarized from Neves (1979), Bane and Lind (1978), and Ragland (1974) suggest that "typical" freshwater benthic invertebrate dry weight estimates range from 0.02 to 0.60 oz/yd^2, when appropriately converted. For assessment purposes a mean dry weight biomass of 0.50 oz/yd^2 has been assumed for all potentially affected macroinvertebrate populations. These estimates will be used to determine the invertebrate productivity loss for each of the spill scenarios where coal particles would be expected to settle on the stream bottom to a depth of approximately 0.3 inches, or greater.

The anticipated secondary impacts of this invertebrate productivity reduction on affected fishes would be a similar decrease in fish food availability. If a fish is assumed to be approximately 15 percent efficient in converting its food to flesh (Russel-Hunter 1970) then, for every yd^2 of substrate covered, approximately 0.08 oz. (dry weight) of fish flesh would be "lost." It should be noted that these productivity estimates are very liberal in order to present the "worst-case" data in a quantitative fashion. Potential invertebrate and fish biomass loss estimates are provided in Table 4-41.

One potential consequence of slurry spills which can not be credibly quantified concerns the potential bioaccumulation of toxic metals in invertebrates which may indiscriminately feed on coal particles. This phenomenon has been recently documented for invertebrate populations exposed to a coal ash spill in a South Carolina river (Cherry et al. 1979). Tables 2-4 and 2-5 adequately demonstrate the presence of light and heavy metals in coal samples from the Wyoming mine sites.

Some bioaccumulation of these metals would be anticipated in the affected invertebrates and other organisms in the food web which feed on them. It is not possible at this time, however, to quantify this impact.

Table 4-42 summarizes the aquatic biological impacts anticipated at the various spill scenario sites. A short narrative discussion of these anticipated impacts is presented under each spill scenario heading below.

Terrestrial Impacts

For the most part, terrestrial impacts resulting from spills are anticipated to be insignificant (Rogozen et al. 1977; OTA 1978; Rogozen et al. 1978). Where the pipeline traverses other than wetland habitat, the spill would probably affect less than 75 acres of vegetative habitat. Such a spill would result in the loss of some animals (i.e., rodents) and displacement of others. Small mammals, reptiles, and amphibians may not be able to escape the advancing slurry and burrowing animals could be smothered or drown as they tend to retreat to their burrows when threatened. Displaced animals could be subjected to competitive stress. If the spill were to occur during reproductive seasons, ground-nesting bird nests could be destroyed. The loss of these terrestrial system components and others would be locally severe but have minimal effects on regional populations. Following cleanup and restoration of the area, rapid recolonization and reestablishment of pre-perturbation populations levels is expected.

TABLE 4-41

ESTIMATES OF MACROINVERTEBRATE AND EQUIVALENT FISH FLESH BIOMASS THAT MAY BE LOST AS A RESULT OF PARTICULATE COAL DEPOSITION AT COAL SLURRY SPILL SITES

River Substrate Area Covered (yd^2)	Macroinvertebrate Biomass (lb, dry weight)	Fish Biomass (lb, dry weight)
10	0.3	0.05
20	0.6	0.1
50	1.6	0.2
100	3.1	0.5
500	15.6	2.5
1,000	31.2	5.0
2,000	62.4	10.0
5,000	156.0	25.0
10,000	312.0	50.0

Note: See text for discussion of assumptions.

TABLE 4-42

QUANTITATIVE COMPARISON OF ANTICIPATED AQUATIC BIOLOGICAL IMPACTS AT THE VARIOUS SPILL SCENARIO SITES

Impact Category		Site 1 (N. Platte River)				Site 2 (Sand Creek)				Site 4 (Illinois River)				Site 5 (Cedar Bluff Res.)	Site 6 (Saline River)				Site 7 (Bayou Cocodrie)			
		High Flow		Low Flow		High Flow		Low Flow		High Flow		Low Flow			High Flow		Low Flow		High Flow		Low Flow	
		CR	OR	CR	OR	CR	OR	CR	OR	CR	OR	CR	OR	CR or OR	CR	OR	CR	OR	CR	OR	CR	OR
Maximum temperature change expected (^{o}C)		0.0	0.0	6.1	1.6	6.1 4.1	0.4	12.4 13.8	10.2 11.3	0.1	0.1	7.0	0.8	10.1 13.4	0.1	0.1	0.7	0.1	0.1	0.1	0.3	0.1
Heat or cold shock (at least $3^{o}C$ change)		No	No	Cold	No	Heat or Cold	No	Heat or Cold	Heat or Cold	No	No	Cold	No	Heat or Cold	No	No	No	No	No	No	No	No
Dissolved oxygen stress anticipated (DO below 5 mg/l)		No	No	No	No	No	No	Yes (0.7)	Yes (2.0)	No	No	No	No	Yes (Near 0)	No	No	No	No	Yes (3.0)	Yes (3.0)	Yes (4.9)	Yes (4.9)
Suspended solids emigration (ft)		>10,000	100	>10,000	>10,000	>10,000	50	>43,000	>36,000	50	50	>4000	>400	varies	500	50	400	50	50	50	50	50
Time to move (hr)		1	5	1	1	1	1	6	10	1	1	1	1		0.5	1	0.5	1	0.3	1	0.3	1
Sedimentation mortality (lb, dry weight)	Fish	No	No	No	No	No	No	No	0.3	No	No	4.7	0.07	varies	0.7	1.0	No	No	3.2	2.4	>0.2	0.2
	Invertebrates								1.7			13.2	0.4		4.9	6.4			21.3	16.1	>1.3	1.3

CR = Complete rupture.
OR = Orifice rupture.

Losses of prey in the spill area and the presence of spilled slurry could affect the distribution of predators. However, since predators usually have large home ranges over which they hunt, loss of a small portion would have negligible impacts.

The only water quality characteristics of the slurry water which would be anticipated to cause any wildlife or vegetation damage would be the maximum total dissolved solids and sulfate concentrations of 1940 and 1100 mg/l, respectively. Wildlife drinking the slurry water would probably experience a slight laxative effect (U.S. EPA 1976).

It is possible that toxic metals known to occur in the coal particles (Tables 2-4, 2-5) could be ingested by wildlife drinking the slurry water. This impact should be considered insignificant, however, since the slurry water would be available for consumption for only a short period of time (generally less than 24 hours), and the coal particles would be expected to pass through the digestive tract in an equally short period of time.

Wetland Impacts

Coal slurry spills into wetland areas would generally affect greater amounts of wildlife habitats than for other environments and because of their lower abundance, the impacts would be more severe. Slurry spills can result in the destruction or long-term alteration of these wetland habitats and in areas where wetlands are scarce a spill could cause regionally significant biological impacts.

Table 4-43 lists five wetland areas where a slurry spill could have a significant, long-term impact. A slurry spill in wetlands habitat could result in the destruction or permanent alteration of the wetland. Because of the scarcity of wetland habitat in Kansas, such a loss would be considered long-term and significant. A spill between MP C-315 and C-325 of the Colorado alternative could contaminate some greater prairie chicken strutting habitat. According to the Colorado Division of Wildlife, any loss of strutting habitat would be a significant impact to this state protected species.

In most wetland spill situations the slurry particles would settle rapidly near the point of entry due to the lack of water currents and thus limit the impacts to only a portion of the total wetland area. If the spill source is close to the wetland many of the channels near the point of entry may be blocked and some of the above water areas could be buried. The resulting impacts would be severe but very localized. Displaced fish and mammals would emmigrate to other areas of the wetlands. However, wetlands are natural sediment traps and are periodically subject to high sediment loads during periods of heavy storm induced runoff. Spills occuring at a distance from the wetland should have much the same impacts as would high turbidity storm runoff as much of the coal particle content will have settled out before reaching the wetland.

TABLE 4-43

TERRESTRIAL SITES WHERE SLURRY SPILLS[a] COULD HAVE A LONG-TERM SIGNIFICANT IMPACT

Route/MP	Concern
Proposed Action	
P-551	Wetlands
P-567	Wetlands
P-593	Wetlands
Colarado Alternative	
C-315 to C-325	Greater prairie chicken
C-558	Deception Creek

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[a] Assuming that the affected area from a slurry line rupture would be 75 acres. The sensitivity of each of these areas is described in detail in the Terrestrial Biology Technical Report (Woodward-Clyde Consultants 1981b).

Spill Scenarios

Scenario 1 - North Platte River.

High Streamflow Conditions. As indicated in Table 4-42, the hydraulic spill model developed suggests that coal particles would not settle out of the water column in the channel of the North Platte River. Some particle settling would, of course, be expected to occur in backwater areas and along sand bars but these settling characteristics cannot be quantified and, therefore, the associated biological impacts cannot be quantitifed.

Neither temperature nor dissolved oxygen stress would be anticipated under high streamflow conditions.

Under orifice rupture conditions affected fishes would be expected to move at least 100 feet downstream from the spill location within five hours of the time the pipeline ruptures in order to avoid suspended solids concentrations in excess of approximately 70,000 mg/l. Fishes which migrate away from concentrations in excess of 70,000 mg/l would not be expected to suffer any significant long-term impacts.

If eggs, larval fishes, or adult fishes were subjected to suspended solids concentrations of 70,000 mg/l, or more, and could not avoid the spill plume they might be killed.

Migrating rainbow trout would be expected to avoid the spill plume and would probably resume their migration "runs" after spill completion.

Invertebrates capable of swimming, drifting, or crawling away from the plume (primarily aquatic insects) would be expected to do so. Those not capable of avoiding the plume would be expected to survive on reduced oxygen intake (due to gill membrane protection behavior) for the duration of the spill.

Under complete rupture conditions, impacts similar to those described above would be expected except that the area of impact would be greater. In order to avoid high suspended solids concentrations, biota would have to migrate more than 10,000 feet downstream (or any distance upstream and out of the spill plume) within the first spill hour. Clearly, not all affected biota could move such distances and, accordingly, spill mortality would be greater under complete rupture conditions.

Low Streamflow Conditions. No dissolved oxygen stress would be anticipated as a result of either a complete or orifice rupture in the North Platte River under low streamflow conditions, since the dissolved oxygen concentration would not be expected to decrease to 5.0 mg/l, or lower.

Neither heat shock nor cold shock would be expected to result from an orifice rupture. Cold shock could be experienced, however, under complete rupture conditions. A complete rupture could decrease the ambient river temperature by approximately 6.1°C to a distance of approximately 7000 feet downstream from the spill site. Fishes and invertebrates affected by this thermal plume (in addition to elevated suspended solids concentrations) would probably be killed.

Under both orifice and complete rupture conditions, biota would have to migrate more than 10,000 feet within the first spill hour in order to avoid suspended solids concentrations in excess of 70,000 mg/l.

The hydraulic models indicate that coal particles would not be expected to settle out of the water column in the North Platte River channel. No sediment mortality estimates, therefore, have been provided. Invertebrate mortality, however, would probably be limited to those slow- or still-water habitats where some particles would settle on the river bottom.

Scenario 2 - Sand Creek. Sand Creek was chosen as a spill site not only because it was considered typical of Arkansas darter habitat, but also because it was a small stream. It was perceived to be more representative of physical conditions at the majority of pipeline stream crossings than any major rivers which would be crossed by the pipeline. As demonstrated by the data in Table 4-42, and the discussion which follows, this concern for small streams was well-founded.

High Streamflow Conditions. No dissolved oxygen stress or sedimentation mortality would be anticipated under high streamflow conditions for either complete or orifice ruptures.

Neither heat shock nor cold shock would be anticipated as the result of an orifice rupture. Either heat shock or cold shock could be expected, however, as the result of a complete rupture. The temperature extremes indicated in Table 4-42 could probably be experienced for an area extending approximately 1400 feet downstream from the spill site. Fishes and invertebrates not capable of avoiding this thermal (and suspended solids) plume would probably be killed.

Under complete rupture conditions, biota would have to migrate at least 10,000 feet downstream (or any distance upstream from the spill site) within the first spill hour in order to avoid suspended solids concentrations in excess of 70,000 mg/l. Under orifice rupture conditions, biota would be expected to migrate 50 feet downstream in the first spill hour in order to avoid concentrations in excess of 70,000 mg/l.

Low Streamflow Conditions. Under orifice or complete rupture conditions it is anticipated that most fishes and invertebrates within 36,000 and 43,000 feet downstream from the spill site would be killed as a result of thermal shock, dissolved oxygen stress, sedimentation smothering, and/or elevated suspended solids concentrations (Table 4-42). This impact would be localized, short term, and biologically significant with stream recovery expected within two to three years after spring floods have scoured coal particles out of the streambed.

Scenario 3 - Recreational Area.

Recreational use of this area would probably diminish following a coal slurry spill due to the impacts on the area's aesthetics and the reduction in the size of the area available for use. These impacts would persist only until cleanup and restoration of the affected area is completed.

Relatively small amounts of wildlife are anticipated to be affected by a slurry spill. The speed of a spill through the area would preclude the escape of most small mammals (i.e. mice, moles, etc.). If the spill occurred during reproductive seasons, some ground-nesting bird nests may be smothered. Some larger members of the terrestrial fauna (i.e. rabbits) may also be affected in the immediate spill area. Although these animals are capable of escape, they tend to retreat to burrows when threatened. The loss of these components of the terrestrial system, although locally severe, would have minimal effects on the regional population levels. Following cleanup and restoration of the area, small mammals and birds would quickly recolonize the area and local populations would quickly recover to pre-perturbation levels.

Losses of prey in the spill area and presence of coal slurry could affect the distribution of predators such as fox and coyotes. However, since predators usually have large home territories over which they normally range, losses of a small portion would have negligible impacts.

Scenario 4 - Illinois River.

High Streamflow Conditions. As indicated in Table 4-42, the hydraulic spill models developed suggest that coal particles would not settle out of the water column in the channel of the Illinois River although some particles would be expected to settle in slackwater habitats. Sedimentation mortality would not be expected to be significant under these conditions.

Neither temperature nor dissolved oxygen stress would be anticipated under high streamflow conditions.

Under orifice and complete rupture conditions affected fishes would be expected to move at least 50 feet downstream from the spill location within one hour of pipeline rupture in order to avoid excessive (greater than 70,000 mg/l) suspended solids concentrations.

Impacts to those biota not capable of avoiding the spill plume were described in the Scenario 1 discussion and the Aquatic Impacts section, above.

Low Streamflow Conditions. In the case of an orifice rupture neither thermal shock nor dissolved oxygen stress would be anticipated to result in significant biological impacts.

Elevated suspended solids concentrations, however, would probably cause the emigration of affected biota more than 400 feet downstream (or any distance upstream) from the spill site within the first spill hour. Any biota not capable of avoiding the spill plume could be killed.

Sedimentation mortality would be anticipated to kill approximately 0.4 pounds (dry weight) of benthic invertebrates with an equivalent fish flesh loss of approximately 0.07 pounds (dry weight).

Under complete rupture conditions dissolved oxygen stress would not be anticipated since concentrations would be expected to remain above 5 mg/l. Cold shock, however, could kill fishes and invertebrates within approximately 5000 feet downstream from the spill site if they could not, or would not, emigrate from the thermal plume.

Biota would be expected to emigrate at least 4000 feet to avoid suspended solids concentrations in excess of 70,000 mg/l and, as indicated above, would probably move at least another 1000 feet to avoid the thermal plume. Any biota not capable of avoiding the plume could be killed.

Sedimentation effects would be expected to kill approximately 31.2 pounds (dry weight) of invertebrates, which could result in the equivalent loss of about 4.7 pounds (dry weight) of fish flesh.

All of the anticipated low streamflow rupture impacts would be considered significant, localized, short-term impacts. Habitat and biological recovery would be expected after spring high flows scour the streambed and invertebrates colonize the previously covered substrate. Fishes would be expected to reestablish their populations from both upstream and downstream locations.

Scenario 5 - Cedar Bluff Reservoir.

Variables including reservoir operation, thermocline number and depth, reservoir currents (wind or "turnover" induced), organism distribution, and potential spill stratification make it difficult to predict sedimentation mortality and suspended solids emigration impacts with any degree of confidence. For instance, settling of the coal particles would be expected to kill invertebrates only where aerobic substrate conditions prevail, a phenomenon which may vary seasonally and with watershed drainage.

Suspended coal particles, similarly, could be restricted to particular thermocline water strata. Nevertheless, affected biota would be expected to emigrate to spill areas with suspended solids concentrations less than 70,000 mg/l. Biota incapable of avoiding such concentrations could be killed.

Under worst case conditions it is anticipated that heat shock or cold shock could occur, and dissolved oxygen stress could also occur. Affected biota would be killed since these physicochemical conditions would be expected to be severe (Table 4-42).

Scenario 6 - Saline River.

High Streamflow Conditions. Neither thermal shock nor dissolved oxygen stress would be anticipated as a result of either complete or orifice rupture.

In order to avoid suspended solids concentrations greater than 70,000 mg/l, affected biota would be expected to migrate approximately 500 feet downstream (or any distance upstream) from the complete rupture spill site within 0.5 hours of the time of rupture. Under orifice rupture conditions the downstream migration required could be approximately 50 feet within the first spill hour.

Sedimentation phenomena could be expected to kill 4.9 pounds and 6.4 pounds (dry weight) of invertebrates under complete and orifice rupture conditions, respectively. The anticipated equivalent fish flesh biomass loss would be approximately 0.7 pounds and 1.0 pounds (dry weight) under complete and orifice rupture conditions, respectively.

Low Streamflow Conditions. Under low flow conditions coal particles would not be expected to settle out of the water column (Table 4-42) and, therefore, sedimentation mortality would only be expected to occur in backwater or stillwater habitats in the Saline River. Quantitative estimates are not possible under these conditions.

Under complete or orifice rupture conditions aquatic biota would be expected to move at least 400 feet in approximately 30 minutes, or 50 feet in approximately one hour, respectively, in order to avoid suspended solids concentrations of 70,000 mg/l or greater. Those biota successful in avoiding the plume would not be expected to suffer any significant impacts. Impacts on biota subjected to plume conditions were discussed above.

No dissolved oxygen stress or thermal shock would be anticipated in the Saline River as a result of a coal slurry spill.

Scenario 7 - Bayou Cocodrie.

High Streamflow Conditions. The sluggish nature and tendency toward low dissolved oxygen levels (5.0 to 9.0 mg/l) in bayous makes them relatively more sensitive to spill impacts than fast-flowing, well-oxygenated streams and rivers.

As indicated in Table 4-42, no significant temperature stress would be anticipated under either complete or orifice rupture conditions.

Dissolved oxygen stress, however, could occur and it is estimated that ambient oxygen levels could drop to approximately 3.0 mg/l in Bayou Cocodrie if a spill were to occur. This anticipated oxygen concentration, in conjunction with greatly elevated suspended solids concentrations in the immediate vicinity of the spill, would be expected to kill fishes and invertebrates which could not leave the affected area. Affected biota could avoid a significant portion of the plume, however, by moving at least 50 feet downstream (or any distance upstream from the spill site) within 15 to 60 minutes of pipeline rupture.

Invertebrate sedimentation mortality would be expected to equal approximately 21 pounds and 16 pounds (dry weight) under complete rupture and orifice rupture conditions, respectively. The anticipated equivalent fish flesh biomass loss would be 3.2 and 2.4 pounds (dry weight), respectively.

Low Streamflow Conditions. No temperature stress would be anticipated as a result of either complete or orifice pipeline ruptures.

Dissolved oxygen stress could occur although the anticipated decrease in oxygen concentration would only be 0.1 mg/l. The anticipated during-spill concentration would be approximately 4.9 mg/l and it is unlikely, even in conjunction with elevated suspended solids concentrations, that significant mortality would result.

It is anticipated that fishes and invertebrates would have to move approximately 50 feet downstream (or any distance upstream from the spill site) in 15 to 60 minutes in order to avoid suspended solids concentrations in excess of 70,000 mg/l.

Under both complete and orifice rupture conditions invertebrate sedimentation mortality would be approximately 2.0 and 1.3 pounds (dry weight), respectively. The approximate equivalent fish flesh loss would be 0.3 and 0.2 pounds (dry weight), respectively.

Scenario 8 - Bottomland Hardwoods

This scenario contains both terrestrial and wetland areas but was selected primarily because this type of wetlands typifies the majority of those found along the pipeline route. The impacts of a coal slurry spill on the terrestrial areas would be similar to those discussed in Scenario 3 but would be more significant for the wetland areas.

Because of their unique qualities, wetlands support a variety of plants and wildlife not typically found in abundance in the area. The number and diversity of habitats within the wetlands is large and are often sensitive to disruption. A large slurry spill could destroy these habitats, plants, and wildlife and disrupt the wetland system in general.

Small amphibians, reptiles and fish may not be able to escape the advancing slurry and could be smothered by settling coal particles or succumb to the effects of extremely high turbidity. Although wetlands serve as a natural sediment trap and receive high sediment loads from surface runoff, slurry spills could fill in channels and cover over relatively large areas with coal particles, thus destroying the habitats within those areas.

The above impacts are generally considered very significant and long-term in most wetland areas and could be accentuated if recovery of the slurry were attempted. However, the large area occupied by the bottomland hardwood would tend to moderate the impacts, as dispersion of the spill would not be expected to affect a significant portion of the available habitat.

Ancillary Aquatic Spill Scenario Site - Deception Creek. One spill site which was preliminarily considered for spill impact analysis but eliminated due to insufficient historical hydrology and water quality data was Deception Creek, Barton County, Kansas. The Colorado alternative slurry pipeline would cross Deception Creek (MP 558) approximately 10 miles upstream from the Cheyenne Bottoms State Waterfowl Refuge, which is considered to be critical habitat for whooping cranes and other migrating waterfowl (Queal and Wood 1980), and is a nesting area for the interior least tern.

Deception Creek is a small, intermittent, prairie stream with deep-cut banks, occasional deep pools, and a predominantly sand-silt substrate. A coal slurry spill in this stream would be anticipated to behave similarly to a rupture in Sand Creek (Scenario 2), except for the ultimate fate of the coal particles. The ultimate destination of these coal particles would be anticipated to be the confluence of Deception Creek with the marshy delta of Cheyenne Bottoms. The Bottoms would be expected to act as a "sediment trap" for the coal.

The biological impacts anticipated would include general decrease in community productivity (through direct localized mortality or emigration of aquatic biota), and the accumulation of metals in invertebrates (and other aquatic biota), which are waterfowl food organisms.

No direct impacts on waterfowl are anticipated as a result of potential water quality changes for the reasons cited in the general discussion of terrestrial impacts, above.

Summary

Significant biological impacts anticipated as a result of the various spills would generally be confined to aquatic habitats, except for the terrestrial sites identified in Table 4-43.

Depending on the spill location, season, and sensitivity of the affected biota, significant aquatic biological impacts could include (1) approximately 85 percent mortality of fish eggs and larvae in the affected river area, (2) smothering of benthic macroinvertebrates and substrate habitat, or at least emigration from affected substrate areas, (3) heat shock or cold shock fish and invertebrate kills, (4) bioaccumulation of some toxic metals, (5) low dissolved oxygen tension stress, and/or (6) decreases in invertebrate and fish productivity in the affected areas.

It should be noted that these are "worst-case" analyses and it is not likely that even two of these impacts would occur at any single spill location.

The specific spill scenario site data tend to substantiate the theory that, in general, spills in "small" streams or under low streamflow conditions cause more reverse biological impacts than spills in large rivers or under high streamflow conditions.

4.B.5 OTHER IMPACTS

Other impacts include the disruption of surface water supplies. The significance of such an impact will vary substantially with the spill volume and location relative to the water intake and whether the water is used for agricultural, industrial, or domestic purposes. In most cases impacts would be minimal as the downstream travel time of the spill would allow the majority of users to be notified to temporarily discontinue withdrawals. Under these circumstances a spill is anticipated to render a stream or river "contaminated" for a period roughly equivalent to the duration of the spill or a maximum of about 24 hours.

A substantial number of water intakes have been located downstream of pipeline crossings over the entire ETSI pipeline route. The vast majority of these are agriculturally oriented, with only a few identified as being industrial or domestic. The impact of entrained slurry-contaminated water on industrial users is uncertain. While cooling water should not be affected, contaminated process water may be unacceptable.

Short term disruption of domestic withdrawals could be expected to cause local hardship and even require temporary use of alternate supplies (wells) or transportation of drinking water until health department officials certify the source as fit for consumption. Agricultural users would remain relatively unaffected even if crops were to be accidentally irrigated with slurry contaminated water. In this case, the slurry is expected to be highly diluted and is not considered toxic to vegetation. Some buildup of total dissolved solids in the soil would be expected but this impact is considered insignificant.

4.C UNAVOIDABLE IMPACTS

Spills entering surface waters will cause the mortality of at least a portion of the biota in the immediate vicinity of the spill as well as areas downstream. An aesthetic impact is created by the coal in suspension, temporarily turning the receiving water black.

In the case of lakes, settled coal would be added to the permanent bottom sediments. Reducing conditions in the coal sediment layer could potentially result in the release of trace metals in soluble forms thereby altering the water quality in the area of the sediment/water interface. In addition, the settled coal, if present in large quantities, would reduce the storage capacity of small impoundments.

The unavoidable impacts of a terrestrial spill would depend primarily on their size and location. In the case of moderate to large spills, some small animals, primarily rodents, and/or their habitats lying in the path of the spill would likely be destroyed. Such impacts, however, would not affect their population as a whole. Vegetation within the path of the spill, especially near the source, would be buried or coated by the slurry and, in the case of burial, could take several years to recover. Hydraulic sediment erosion by the spilling slurry is also expected near the source.

Terrestrial spills would create a significant aesthetic impact if the spill were large and situated in a highly visible area. The settled material would form a black mass with the areal extent and thickness dependent upon spill volume, relief of the surrounding terrain, vegetation density and presence of natural impoundments. If the coal is not removed it could persist for several years before being dispersed by the winds and surface runoff. However, the Black Mesa spill, discussed in Section 1.C, resulted in only scattered pockets of the 1200 tons of coal spilled remaining in the dry washes five months after the spill occurred.

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PSI

APPENDIX

Technical Report
on
Potential Pipeline Spills
by the
ETSI Coal Slurry Pipeline

Prepared for
Woodward-Clyde Consultants

July 1980

Pipeline Systems Incorporated

San Francisco Office
61 Avenida de Orinda
Orinda, California 94563
415·254·4420

1. Introduction and Summary

The potential pipeline spill frequencies, spill volumes and rates of discharge are the important parameters needed by all disciplines evaluating the possible impacts of accidental pipeline discharges to the environment. This report presents the potential quantities and rates of product discharge for selected leak locations along the ETSI Coal Slurry Pipeline. It also presents a summary of government data showing the probable spill frequencies based on liquid pipeline spill statistics gathered on interstate pipelines by the Department of Transportation.

It cannot be emphasized too strongly that the likelihood of any of the line breaks evaluated ever occurring, let alone the volumes projected ever actually being discharged from the break, is extremely remote. This report presents the results of mathematical calculations under a specified set of conditions. It is not a projection of what might happen in the real ETSI system. The following factors were not considered in the calculations, but would have a significant impact on the possibility of drainage from a leak in the ETSI system.

- Six of the eight spill sites evaluated are at rivers. River crossings require special design considerations which reduce the probability of a line break at that point to far below the overall average.
    - Heavier wall thickness pipe at river crossings means that incorrect operation would result in line failure at another, weaker, location.

- The probability of equipment rupturing the line is reduced due to much reduced equipment activity. Also, the line will frequently be concrete-coated, further reducing the risk of equipment rupturing.

- All girth welds must be radiographically tested when they are installed in "river, lake, and stream crossings within the area subject to frequent inundation; and river, lake, and stream crossings on bridges..."(2) reducing the probability of defective welds.

- This evaluation assumes that there are no valves installed between pumping stations. Line valve locations selected during detailed design could greatly reduce potential spill volumes.

- The average 24-hour draindown volume from a complete rupture for the eight spill scenarios evaluated is 153,000 barrels. The 1968 to 1974 average petroleum pipeline spill volume for the 2395 reported incidents was 1058 barrels.(1) These data further depreciate the reality of the volumes projected in this study.

- The spill volume projections assume that no mitigating steps are taken after the line break, beyond shutting down the line and letting it drain. There are few cases where nothing can be done to slow, stop, or mitigate the effects of a leak before complete draindown.

2. Anticipated Spill Frequency for Coal Slurry Pipelines

Accidental leakage reports involving slurry pipelines are not required by the U.S. Department of Transportation's

Office of Pipeline Safety Operations (OPSO) because of their low-hazard nature. At present there is only one coal slurry pipeline in operation in the United States. To date no published spill data are available for this pipeline. As a result, coal slurry pipeline accidental spill frequencies must be derived from accident reports for hazardous liquid pipelines filed with OPSO. All accidents involving interstate hazardous liquids, resulting in more than 50 barrels of liquid spill, or involving casualty, fire, explosion, or greater than $1000 property damage to third parties, must be reported to the OPSO on form 7000-1.

From 1968 to 1976, 2859 accidents involving interstate liquids pipelines were reported (2294 involving only line pipe). In 1976, the latest year for which official statistics were published, 169 accident reports were filed for line pipe alone (209 accidents for all areas). The trends in the categories of line pipe accidents can be seen in Table A-1.

Table A-1 ACCIDENTS INVOLVING LIQUIDS
LINE PIPE ONLY

ACCIDENT	ACCIDENTS REPORTED		PERCENTAGE	
CAUSE	1968-76	1976	1968-76	1976
Corrosion	1024	50	45	30
Equipment Rupturing Line	635	63	28	38
Defective Pipe	165	14(1)	7	8
Defective Girth Welds	125	4(1)	5	2
Incorrect Operations	53	4(1)	2	2
Other	292	34(1)	13	20
TOTAL	2294	169	100	100

**See Source on Following Page

** Source: National Transportation Safety Board, Special Study - Safe Service Life for Liquid Petroleum Pipelines.
(1) From Figure 3 of source report.

Equipment rupturing the pipeline has replaced corrosion as the major cause of pipeline accidents. Corrosion-induced spills have steadily decreased since 1969, probably as a result of federal regulations requiring that cathodic protection systems be installed on all coated pipelines by March 31, 1978.

Since the ETSI pipeline will be coated and cathodically protected, it would be most accurate to utilize accident data for similarly protected pipelines. However, data pertaining to total miles of corrosion-protected versus non-protected pipelines are not available from the OPSO.

The problems associated with the quality of new pipe and its installation, as shown in the above data, are small in number relative to other categories.

The percent of the total accidents caused by incorrect operation by pipeline carrier personnel has steadily increased since 1968, as have accidents due to vandalism, weather and equipment failure, all of which are included under the "other" causes category.

Table A-2, which shows the data on Table A-1 on a yearly basis, puts the line pipe accident picture in perspective with the overall pipeline system accident record. Table A-2 also shows that the annual total pipeline system accidents are decreasing.

Table A-2 LIQUIDS PIPELINES - ALL ACCIDENTS(1)
YEARLY ACCIDENT SUMMARY - 1968-1976

CAUSE	1968	1969	1970	1971	1972	1973	1974	1975	1976
Corrosion	232	172	179	124	100	86	67	72	51
Equipment Rupturing line	98	90	70	67	69	66	78	73	67
Defective Pipe	36	35	32	31	32	21	20	15	14
Defective Welds	4	3	3	3	5	5	4	5	4
Incorrect Operations	14	13	13	22	22	16	28	22	20
Other	115	90	50	61	81	79	59	68	53
TOTAL:	499	403	347	308	309	273	256	255	209

Source: U.S. Department of Transportation, Office of Pipeline Safety Operations

(1) Yearly accident numbers include all pipeline facilities, including line pipe.

The above discussion has investigated the causes and total numbers of accidents per year. Table A-3 shows the calculated yearly number of accidents or leaks per mile for the 1968 to 1976 period.

TABLE A-3 REPORTED LINE PIPE ACCIDENTS ALL CAUSES - ALL PRODUCTS

YEAR	REPORTED NUMBER OF ACCIDENTS(2)	REPORTED NUMBER OF TRUNK PIPELINE MILES	ACCIDENTS PER MILE
1968	421	115,238	.0037
1969	350	117,983	.0030
1970	288	122,365	.0024
1971	258	122,471	.0021
1972	235	124,458	.0019
1973	194	122,354	.0016
1974	199	126,211	.0016
1975	180	121,278	.0015
1976	169	(1)	(1)

Source: National Transportation Safety Board, Special Study - Safe Service Life for Liquid Petroleum Pipelines.

(1) Data not yet available from ICC Part 6 Report.

(2) Note that these figures are for line pipe only and do not include pump station or related facilities accidents.

This summary includes pipe of all ages, and all pipelines, whether cathodically protected or not, and whether coated or bare pipe.

When the annual accident-per-mile data verses the yearly data from Table A-3 are fitted to a power law equation, the trend in accidents per mile is easily seen. This trend would indicate that annual rates on the order of 0.001 accidents per mile of pipeline will be the norm for the mid 1980's. Because the ETSI pipeline will be new, it is expected that it will not have any greater yearly accident rate than the predicted national annual rate of 0.001 per mile. Therefore, using the national average for all pipelines and around 1800 miles of installed pipeline in the ETSI case, a likely leak frequency scenario would be on the order of two leaks per year for the system. In interpreting this number, one must keep in mind that the ETSI system will be new and will be utilizing state-of-the-art technology and should be in a position to operate at less than this frequency.

3. Leak Detection

ETSI proposes to detect, identify, or prevent spills by one of the following methods:

- Aerial reconnaissance
- Ground patrols
- Third party reports
- Coal slurry metering

The question arises as to the effectiveness of the above methods in limiting spill sizes. In order to evaluate how effective each of these methods might be, it is imperative to have some grasp of the possible spill situations that might arise.

Review of actual or simulated coal slurry pipeline leaks indicates that for holes less than one quarter of an inch, coal particles immediately plug the hole and leakage stops until a water batch passes when the hole may leak water. If a leak has not been detected by the time slurry returns to the line, the leak may stop again. This cycle could continue indefinitely unless the hole is either discovered or grows larger. Leaking slurry would in most cases enlarge the hole after a period of time. Although coal is not extremely abrasive, there is data showing that at high velocities carbon steel is removed with time. Small leaks of this nature can be caused by any of several things (including but not limited to corrosion, excavation equipment, farm plows, and defective pipe).

Once a small hole has developed, one needs to evaluate how long the leak can go undetected. Leaks will ultimately be reported by a third party or coal slurry metering. ETSI will be relying on aerial and ground patrols to detect activity near the line and alert outside workers of the existence of the pipeline. These patrols will also locate small leaks before they are large enough to be detected by the slurry metering systems.

Table A-4 is a leak detection matrix that shows the hole size that could develop before detection by the slurry metering systems, given different pipeline flows and internal pressures. ETSI is planning to measure differences in flows between pump stations to an accuracy of 1.5 percent of the flowrate. Given this 1.5 percent criterion, the hole size at detection is estimated to be less than one inch in diameter. These numbers were developed using a range of possible steel wear rates and velocity through the hole in the pipe. In all cases the hole was modeled as a round orifice type. If one assumes that a one quarter-inch hole is the size at which slurry begins to leak, then high and low wear rate scenarios, combined with different internal line pressures and flows, are used to estimate possible undetected spill sizes. The range of times to detection as

TABLE A-4

LEAK DETECTION MATRIX(1)

Possible Scenario for 0.250-inch Leak Size

P/L Flows (gpm)	Pressure (psig)	Hole Size (in)	Hole Size At Detection (in)	Time Range (hrs)(2)		Est. Max. Material Loss Before Instr. Detection (bbl)	
				High Wear	Low Wear	High Wear	Low Wear
25,000	1500	0.250	0.595	63	342	34,000	183,000
20,000	1500	0.250	0.532	51	280	22,000	120,000
15,000	1500	0.250	0.461	38	209	12,000	67,000
10,000	1500	0.250	0.376	23	125	5,000	27,000
5,000	1500	0.250	0.266	2	16	300	1,700
25,000	1000	0.250	0.658	116	575	62,000	308,000
20,000	1000	0.250	0.589	96	477	41,000	204,000
15,000	1000	0.250	0.510	74	366	24,000	118,000
10,000	1000	0.250	0.416	47	234	10,000	50,000
5,000	1000	0.250	0.294	13	62	1,000	7,000
25,000	500	0.250	0.783	323	1361	173,000	729,000
20,000	500	0.250	0.700	273	1150	117,000	493,000
15,000	500	0.250	0.606	216	910	70,000	293,000
10,000	500	0.250	0.495	149	626	32,000	134,000
5,000	500	0.250	0.350	61	256	7,000	27,000

Notes: (1) Based on leak detection at 1.5% of pipeline flows.
(2) Based on high and low range of steel wear rates.

well as maximum losses are tabulated. This calculation shows that a leak, where the line pressure is above 500 psig, will be detected by flow measurements before it is one inch in diameter.

Holes less than the detection threshold size must be detected by aerial or ground patrol or third parties. The large estimated maximum material loss before detection by differential station flows illustrates the small probability that a small leak would go undetected by patrols or third parties for a long period of time.

4. Spill Volumes After Detection

Once the leak has been detected and the decision to shut down made,(1) the quantity and rate at which material is lost can be estimated.

4.1 Computer Drainage Model Description

A computer model was used to estimate the rates at which a line full of slurry would drain, and the total volumes of liquid and tons of solids that might be spilled if the line were ruptured at a given point. Inputs to the model were

(1) In not all cases is it best to shut down the pipeline immediately after a leak detection. A skilled operator can minimize leak potential in some parts of the pipeline by understanding the hydraulic implications of shutting down. This case will not be covered in this report because of the unknowns involved. In general, the decision of the operators should improve the spill potential scenario.

profile and breakpoint mileposts and elevations, pipe inside diameter, slurry density and saturated volume concentration, a breaktype (either an orifice hole type or complete rupture), and the upstream and downstream pump station locations.

Outputs from the model were total spill volumes, tonnages, and reports of spill volume and coal tonnage verses time. An algorithm was developed to take into account possible settling of solids in the pipeline as velocities in the line drop below the solids deposition level. The solids settling algorithm consisted of a linear relationship between slurry specific gravity and velocity for velocities less than four feet per second. Above four feet per second the slurry was assumed to be homogeneous. The velocities printed on the output listing are the velocities immediately upstream (UPS) and downstream (DS) of the break point. These velocities were used in the flowing slurry specific gravity estimates.

In addition to the above, line pressure at the break point is tabulated verses time. Note that during draindown for the complete rupture cases, the line pressure is zero and for the orifice type ruptures the value is greater than zero.

Assumptions made in the drainage model were as follows:

- The frictional head losses as measured in feet of slurry for a given velocity are constant for the concentrations seen in the pipeline during draindown.
- The pipeline does not plug due to solids accumulation at the low points at low velocities.

- The solids settling algorithm discussed above was used.

- An extrapolation of steel wear rates versus velocity from existing data was made for use in determining the rate at which a hole in a pipe opened due to solid abrasion.

- The size of a hole in the steel pipe increases due to abrasion as a logarithmic function of the velocity of slurry flow through the hole.

- No drainage from horizontal pipe sections occurs.

4.2 Results of Computer Model Analysis of Eight Spill Sites

The eight possibly sensitive spill sites selected by Woodward-Clyde Consultants are:

1) North Platte River, Nebraska. MP PMB-203.5 of Proposed Action at approximate elevation of 3550 feet (Alexandria Map). USGS Station #06686000 near Lisco, Nebraska, is approximately 15 miles from crossing.

2) Sand Creek, Oklahoma. MP MB-348 of Market Alternative at approximate elevation of 725 feet (Enid Map). USGS Station #07174600 at Okesa, Oklahoma, is approximately 10 miles downstream from crossing.

3) Recreational area, Oklahoma (Tallgrass Meadow/ Bottomland Forest). MP PMB-800 of Proposed Action at approximate elevation of 650 feet (Tulsa Map).

4) Illinois River, Okalahoma. MP MB-438.5 of Market Alternative at approximate elevation of 680.0 feet (Fort Smith Map) USGS Station #07196500 near Tahlequah less than one-half mile upstream from crossing.

5) Ceder Bluff Reservoir (unnamed tributary), Kansas. MP C-491.2 of Colorado Alternative, at approximate elevation of about 2425 feet (Great Bend Map). USGS Station #06861500 is located at Ceder Bluff Reservoir near Ellis, Kansas.

6) Saline River, Arkansas. MP PMS-1118 of Proposed Action (El Dorado Map). USGS Station #07363500 near Rye, Arkansas, approximately 15 miles downstream from crossing.

7) Bayou Cocodrie, Louisiana. MP PM-1338 of Proposed Action (Lake Charles Map). USGS Station #07382000 near Clearwater approximately 15 miles upstream from crossing.

8) Bottomland-Hardwoods area, Louisiana. MP PM(NW)-48 of New Roads Lateral (Baton Rouge Map).

For each spill location, a projected spill was produced for a complete rupture and an orifice type rupture. The complete rupture assumed that each pipe upstream and downstream of the breakpoint drained independent of the other. The orifice ruptures drained through a three-inch hole. The three-inch hole was selected as being a realistic size based on equipment-caused holes such as a plow point, dozer, or grader blade or any other puncturing type apparatus. Figures 1 through 16 show the computed results of the two break types at each point. Figures 17-24 show the profiles upon which each case was based. These profiles were produced by ETSI as part of their system description and represent points taken at each 200-foot contour line on USGS 1:250,000 maps.

The output generated is summarized in Table A-5. Of the complete break cases, the largest potential spill was at

TABLE A-5

SUMMARY OF EIGHT SPILL SCENARIOS

Spill Site	Inside Pipe Diameter (in)	Total Volume (bbl)(1)	Total Solids (tons)	Time to Spill (hrs)	Spill Type (2)
North Platte River	45.188	405,000	39,500	9.5	CB
Sand Creek	45.188	95,000	8,100	4.8	CB
Recreational Area	45.188	44,000	3,600	1.6	CB
Illinois River	39.376	52,000	5,200	1.0	CB
Cedar Bluff Res.	45.118	544,000	58,400	16.1	CB
Saline River	31.446	26,000	1,100	6.7	CB
Bayou Cocodrie	13.500	4,000	200	3.1	CB
Bottomland	25.500	51,000	1,400	24+	CB
North Platte River	45.188	393,000	24,700	24+	0
Sand Creek	45.188	92,000	1,700	23.0	0
Recreational Area	45.188	44,000	600	19.3	0
Illinois River	39.376	52,000	900	14.3	0
Cedar Bluff Res.	45.118	443,000	32,000	24+	0
Saline River	31.446	26,000	300	19.5	0
Bayou Cocodrie	13.500	4,000	100	5.0	0
Bottomland	25.500	31,000	500	24+	0

(1) Total volume is complete volume of spill if spill time is less than 24 hours. It is the spill at 24 hours if spill time is greater than 24 hours.

(2) Spill types are complete break (CB) or three-inch orifice type (O).

the Cedar Bluff Reservoir where 544,000 barrels of slurry containing 58,400 tons of saturated coal could be spilled if a complete pipeline rupture occurred. The spill would occur over a period of about 16 hours.

The smallest leak occurred at the Bayou Cocodrie area, where in the case of a three-inch hole, 4000 barrels containing 100 tons of coal were lost.

Table A-5 volumes are based on spills between two adjacent pump stations. No attempts have been made in this report to analyze the impact which placing valves between pump stations has on spill sizes.

5. State-of-the-Art Spill Handling and Size

The spills produced above assumed that no attempts were made to limit their sizes by repairing the pipe or plugging the holes before the line had completely drained.

Generally, repairs to smaller diameter pipes are difficult if not impossible to make if line pressures are above 400-500 psig and the holes larger than one inch. For large diameter pipelines, repairs are very difficult without almost complete draindown. If a crew were to arrive on site before complete draindown, they must be able to pump out or drain material from the "gloryhole" faster than it is being filled, in order to make a repair. For large diameter pipelines this is almost impossible until the line has completely drained.

Repairs of small holes are generally made with a cone and split sleeve or by welding a split sleeve containing a valve onto the pipe. The possibility of using one of these techniques depends on:

- Internal line pressure
- Hole or rupture size and type
- Pipe diameter
- Availability of crew and equipment to perform work
- Accessibility of pipe

In summary, methods for dealing with pipeline leaks are tied directly to the specifics of location, rate, type, the product being leaked, and the general maintenance philosophy. Mobilization times for maintenance crews depend on such factors as time of day, week or year, weather, available transportation and many other unknowns.

For the above reasons it is difficult to say how long it usually takes a repair crew to reach a break site. With good planning, a well-coordinated team should be capable of arriving at most leak sites in two to six hours after report of a spill. Whether they are able to make the repair immediately will depend on the factors mentioned above.

6. Conclusions

Based on the analysis performed for the ETSI system, several conclusions can be drawn that shed light on possible spill scenarios that will develop as the ETSI pipeline is started up and operated.

- The norm for pipeline spill frequencies at the start of the ETSI system operation as reported by the Office of Pipeline Safety should be around 0.001 leaks/pipeline mile-year. ETSI is expected to at least meet the norm and most probably will see fewer leaks than the norm because of advanced control, maintenance and corrosion protection. If ETSI were only to meet the norm for pipeline leaks, two spills of reportable quantity would be anticipated per year (reportable quantity being taken from the Office of Pipeline Safety criteria).

- Spill volumes will depend on many factors surrounding the cause and handling of the spill. These factors include the location of the spill, the pipe and break size, the break type, the availability of maintenance people, and repair techniques used. Generally spills through holes less than one inch in size must be reported by third parties or company reconnaissance rather than pipeline instrumentation. These spills are of indeterminant size and cannot be detected by pump station flow differences. The period of time for detection using pump station instrumentation is a function of the line pressure, pipeline flow, hole size and metal loss as the slurry abrades the hole. This period is generally from a few hours to several weeks. Spills through holes greater than one inch should be sensed immediately by the pump station instrumentation.

- The results of the computer analysis of the eight break sites chosen by Woodward-Clyde Consultants show that differing quantities of slurry could be spilled at the selected sites, some large spills, some small. These cases analyzed were selected to produce some of the worst possible spill sizes and are not necessarily expected to be those spills actually incurred.

- During the detailed design phase of ETSI's development, serious consideration should be given to the possible use of valves at strategic sites, designed to limit spill sizes by isolating pipeline sections to prevent complete draindown and valuable product loss if a rupture occurs.

Reference:

(1) Special Study, "Safe Service Life for Liquid Petroleum Pipelines," National Transportation Safety Board, Bureau of Accident Investigation, NTSB-PSS-78-1.

(2) *Liquid Petroleum Transportation Piping Systems*, ANSI/ASME B.31.4 - 1979.

Figure 1
COMPLETE RUPTURE
CASE

```
                J.RANCH-P.CITY PROPOSED
                NORTH PLATTE RIVER, NEB
     28 JUN 80                                  CHAPMAN
     @11:07:22                                  79-11.2
                MATERIAL                         COAL
                SLURRY DENSITY                   1.142
                SAT VOL CONC                     .476
                SAT SOL DENSITY                  1.298
     PIPE INSIDE DIA(IN)                        45.188
     PIPELINE SECTION - MILEPOST    PMB-91.90 to PMB-231.10
     BREAKPOINT - MILEPOST                     PMB-203.50

     MAX SPILL AFTER  570.0 MINS IS         404739.  BARRELS
     MAX SPILL AFTER  570.0 MINS IS          39527. TONS SAT COAL

SPILL SUMMARY     LINE       FLOW           VELOCITY  MAX CUM SOLIDS
  (MINUTES)     PRESSURE  (CFS)  (GPM)        (FPS)   SPILLED(TONS)
                 (PSIG)                    (UPS)  (DS)
     1              0.   266.64 119676.   16.32  7.62     308.
    60              0.   242.82 108986.   16.32  5.49   17984.
   120              0.    91.05  40866.    3.71  4.47   26987.
   180              0.    87.90  39452.    3.42  4.47   32894.
   240              0.    34.57  15516.    3.10   .00   35790.
   300              0.    29.74  13348.    2.67   .00   37415.
   360              0.    23.87  10712.    2.14   .00   38540.
   420              0.    16.50   7408.    1.48   .00   39210.
   480              0.     9.15   4106.     .82   .00   39471.
   540              0.     2.41   1083.     .22   .00   39526.
   570              0.      .00      0.     .00   .00   39527.
```

Figure 2
ORIFICE RUPTURE
CASE

```
                  J.RANCH-P.CITY PROPOSED
                  NORTH PLATTE RIVER, NEB
             26 JUN 80                               CHAPMAN
             @17:28:40                               79-11.2
                  MATERIAL                            COAL
                  SLURRY DENSITY                      1.142
                  SAT VOL CONC                        .476
                  SAT SOL DENSITY                     1.298
             PIPE INSIDE DIA(IN)                     45.188
             BREAKSIZE(IN)                            3.000

             FINAL HOLE SIZE(IN)                      6.823
             PIPELINE SECTION - MILEPOST    PMB-91.90 to PMB-231.10
             BREAKPOINT - MILEPOST                   PMB-203.50

             MAX SPILL AFTER 1440.0 MINS IS              392597.  BARRELS
             MAX SPILL AFTER 1440.0 MINS IS               24678.  TONS SAT COAL

        SPILL SUMMARY    LINE        FLOW          VELOCITY  MAX CUM SOLIDS
         (MINUTES)     PRESSURE  (CFS)  (GPM)        (FPS)   SPILLED(TONS)
                        (PSIG)                    (UPS) (DS)
              1          674.     4.57   2051.      .41   .00        1.
             60          601.    17.65   7921.     1.58   .00      383.
            120          556.    21.32   9570.     1.91   .00      981.
            180          505.    24.49  10991.     2.20   .00     1806.
            240          472.    27.64  12405.     2.48   .00     2872.
            300          428.    29.98  13456.     2.69   .00     4174.
            360          396.    32.20  14453.     2.89   .00     5684.
            420          363.    33.91  15222.     3.05   .00     7393.
            480          355.    36.52  16389.     3.28   .00     9322.
            540          348.    39.12  17557.     3.51   .00    11555.
            600          321.    40.50  18176.     3.64   .00    14066.
            660          235.    36.64  16447.     3.29   .00    16465.
            720          170.    32.31  14504.     1.34  1.07    18146.
            780          144.    30.60  13735.      .65  2.10    18989.
            840          132.    29.88  13410.      .39  2.29    19992.
            900          122.    29.50  13242.      .33  2.32    21051.
            960          114.    29.01  13023.      .30  2.30    22104.
           1020          106.    28.40  12748.      .47  2.08    23122.
           1080           66.    22.76  10217.     1.32   .72    23767.
           1140           40.    17.91   8037.      .76   .85    24097.
           1200           25.    14.37   6449.      .35   .94    24309.
           1260           17.    11.85   5317.      .29   .77    24469.
           1320           11.     9.30   4176.      .22   .61    24573.
           1380            6.     6.49   2913.      .17   .42    24634.
           1440            4.     5.26   2360.      .00   .47    24678.
```

Figure 3
COMPLETE RUPTURE
CASE

```
                J.RANCH-OOLAGAH M ALT
                SAND CREEK, OK
        28 JUN 80                        CHAPMAN
        @11:21:33                        79-11.2
                MATERIAL                 COAL
                SLURRY DENSITY            1.142
                SAT VOL CONC              .476
                SAT SOL DENSITY           1.298
        PIPE INSIDE DIA(IN)              45.118
        PIPELINE SECTION - MILEPOST   MB-250.00 to MB-376.00
        BREAKPOINT - MILEPOST            MB-348.00

        MAX SPILL AFTER  285.0 MINS IS        95386.  BARRELS
        MAX SPILL AFTER  285.0 MINS IS         8071. TONS SAT COAL

SPILL SUMMARY    LINE        FLOW           VELOCITY   MAX CUM SOLIDS
 (MINUTES)     PRESSURE  (CFS)   (GPM)       (FPS)     SPILLED(TONS)
                (PSIG)                    (UPS) (DS)
      1            0.   435.35 195399.   17.12 22.09      503.
     30            0.   108.65  48765.    9.79   .00     4486.
     60            0.    36.08  16195.    3.25   .00     5826.
     90            0.    27.96  12549.    2.52   .00     6583.
    120            0.    25.05  11244.    2.26   .00     7134.
    150            0.    21.31   9566.    1.92   .00     7554.
    180            0.    16.82   7551.    1.52   .00     7839.
    210            0.    11.69   5248.    1.05   .00     7999.
    240            0.     6.08   2731.     .55   .00     8062.
    270            0.      .15     66.     .01   .00     8071.
    285            0.      .00      0.     .00   .00     8071.
```

Figure 4
ORIFICE RUPTURE

```
              J.RANCH-OOLAGAH M ALT
              SAND CREEK, OK
        25 JUN 80                             CHAPMAN
        @18:36:28                             79-11.2
              MATERIAL                        COAL
              SLURRY DENSITY                   1.142
              SAT VOL CONC                     .476
              SAT SOL DENSITY                  1.298
        PIPE INSIDE DIA(IN)                   45.118
        BREAKSIZE(IN)                          3.000
        FINAL HOLE SIZE(IN)                    3.970
        PIPELINE SECTION - MILEPOST     MB-250.00 to MB-376.00
        BREAKPOINT - MILEPOST                 MB-348.00

        MAX SPILL AFTER 1379.0 MINS IS          92280.  BARRELS
        MAX SPILL AFTER 1379.0 MINS IS           1662. TONS SAT COAL

    SPILL SUMMARY    LINE        FLOW           VELOCITY  MAX CUM SOLIDS
     (MINUTES)     PRESSURE  (CFS)   (GPM)        (FPS)   SPILLED(TONS)
                    (PSIG)                     (UPS) (DS)
           1        303.     3.98    1785.      .36   .00         0.
          60        243.     9.50    4263.      .86   .00       139.
         120        203.     9.46    4245.      .85   .00       283.
         180        157.     8.84    3966.      .80   .00       413.
         240        137.     8.64    3878.      .78   .00       531.
         300        124.     8.54    3832.      .77   .00       646.
         360        119.     8.68    3895.      .78   .00       762.
         420        113.     8.74    3923.      .79   .00       880.
         480        107.     8.81    3955.      .79   .00      1001.
         540        102.     8.81    3956.      .79   .00      1122.
         600         79.     7.95    3568.      .72   .00      1234.
         660         68.     7.57    3396.      .68   .00      1328.
         720         59.     7.09    3180.      .64   .00      1412.
         780         33.     5.33    2394.      .31   .17      1474.
         840         28.     5.02    2251.      .35   .10      1510.
         900         24.     4.68    2102.      .42   .00      1541.
         960         20.     4.32    1938.      .39   .00      1569.
        1020         17.     3.94    1768.      .35   .00      1594.
        1080         14.     3.49    1568.      .31   .00      1615.
        1140         11.     3.14    1409.      .28   .00      1633.
        1200          8.     2.85    1280.      .00   .26      1646.
        1260          5.     2.05     921.      .00   .18      1656.
        1320          2.     1.33     596.      .12   .00      1660.
        1379          0.      .00       0.      .00   .00      1662.
```

Figure 5
COMPLETE RUPTURE
CASE

```
               P.CITY-PRYOR PROPOSED
               RECREATIONAL AREA, OK
     28 JUN 80                             CHAPMAN
     @10:57:39                             79-11.2
               MATERIAL                    COAL
               SLURRY DENSITY               1.142
               SAT VOL CONC                  .476
               SAT SOL DENSITY              1.298
     PIPE INSIDE DIA(IN)                   45.118
     PIPELINE SECTION - MILEPOST    PMB-700.00 to PMB-807.50
     BREAKPOINT - MILEPOST                 PMB-800.00

     MAX SPILL AFTER   93.0 MINS IS           44401.  BARRELS
     MAX SPILL AFTER   93.0 MINS IS            3585. TONS SAT COAL

SPILL SUMMARY     LINE        FLOW          VELOCITY  MAX CUM SOLIDS
  (MINUTES)     PRESSURE  (CFS)  (GPM)        (FPS)   SPILLED(TONS)
                 (PSIG)                    (UPS) (DS)
      1              0.   261.63 117428.  20.96  2.61     269.
      5              0.   133.26  59812.   9.82  2.19     843.
     10              0.   127.48  57219.   9.82  1.66    1473.
     15              0.    48.38  21714.   3.20  1.16    1753.
     20              0.    42.78  19200.   3.17   .68    1928.
     25              0.    37.62  16884.   3.14   .25    2090.
     30              0.    34.47  15471.   3.10   .00    2247.
     35              0.    34.06  15286.   3.07   .00    2399.
     40              0.    33.47  15021.   3.01   .00    2547.
     45              0.    32.67  14663.   2.94   .00    2689.
     50              0.    31.87  14303.   2.87   .00    2824.
     55              0.    31.06  13943.   2.80   .00    2952.
     60              0.    30.26  13581.   2.73   .00    3074.
     65              0.    29.45  13219.   2.65   .00    3189.
     70              0.    28.64  12856.   2.58   .00    3299.
     75              0.    27.83  12493.   2.51   .00    3402.
     80              0.    27.02  12129.   2.43   .00    3499.
     85              0.    17.91   8038.   1.61   .00    3570.
     90              0.     5.24   2352.    .47   .00    3585.
     93              0.      .00      0.    .00   .00    3585.
```

Figure 6
ORIFICE RUPTURE

```
                  P.CITY-PRYOR PROPOSED
                  RECREATIONAL AREA, OK
         26 JUN 80                          CHAPMAN
         @17:03:28                          79-11.2
                  MATERIAL                  COAL
                  SLURRY DENSITY             1.142
                  SAT VOL CONC                .476
                  SAT SOL DENSITY            1.298
         PIPE INSIDE DIA(IN)                45.118
         BREAKSIZE(IN)                       3.000
         FINAL HOLE SIZE(IN)                 3.481
         PIPELINE SECTION - MILEPOST     PMB-700.00 to PMB-807.50
         BREAKPOINT - MILEPOST              PMB-800.00

         MAX SPILL AFTER 1159.0 MINS IS           43753.   BARRELS
         MAX SPILL AFTER 1159.0 MINS IS             588. TONS SAT COAL

    SPILL SUMMARY    LINE       FLOW            VELOCITY   MAX CUM SOLIDS
     (MINUTES)     PRESSURE  (CFS)  (GPM)         (FPS)    SPILLED(TONS)
                    (PSIG)                     (UPS) (DS)
          1          183.     1.70    761.      .15   .00        0.
         60          159.     7.35   3299.      .66   .00       82.
        120          142.     7.33   3288.      .66   .00      167.
        180          133.     7.41   3326.      .67   .00      252.
        240          123.     7.43   3336.      .67   .00      338.
        300          114.     7.42   3329.      .67   .00      424.
        360          100.     7.20   3233.      .65   .00      510.
        420           29.     3.92   1759.      .35   .00      555.
        480           10.     2.35   1055.      .14   .08      566.
        540            9.     2.13    954.      .12   .07      570.
        600            8.     2.01    903.      .12   .07      574.
        660            6.     1.87    841.      .11   .06      577.
        720            5.     1.69    757.      .10   .06      579.
        780            4.     1.48    662.      .08   .05      582.
        840            3.     1.40    630.      .08   .04      583.
        900            3.     1.22    547.      .07   .04      585.
        960            2.     1.08    484.      .10   .00      586.
       1020            1.      .73    330.      .07   .00      587.
       1080            1.      .66    294.      .06   .00      588.
       1140            1.      .73    329.      .07   .00      588.
       1159            0.      .00      0.      .00   .00      588.
```

Figure 7
COMPLETE RUPTURE
CASE

Rev. 1

```
            PRYOR-ATKINS JUNC M ALT
            ILLINOIS RIVER, OK
   23 JUL 80                          CHAPMAN
   @08:45:03                          79-11.2
            MATERIAL                  COAL
            SLURRY DENSITY             1.142
            SAT VOL CONC               .476
            SAT SOL DENSITY            1.298
   PIPE INSIDE DIA(IN)                39.376
   PIPELINE SECTION - MILEPOST      MB-410.50 to MB-485.50
   BREAKPOINT - MILEPOST              MB-438.50

   MAX SPILL AFTER   57.0 MINS IS         52350.  BARRELS
   MAX SPILL AFTER   57.0 MINS IS          5248. TONS SAT COAL

SPILL SUMMARY    LINE       FLOW          VELOCITY  MAX CUM SOLIDS
  (MINUTES)    PRESSURE  (CFS)   (GPM)      (FPS)   SPILLED(TONS)
                (PSIG)                   (UPS) (DS)
       1           0.   332.62 149291.  13.62 25.71     385.
       5           0.   132.54  59490.   7.37  8.30    1546.
      10           0.   111.52  50053.   7.32  5.87    2242.
      15           0.    95.89  43038.   7.25  4.09    2827.
      20           0.    86.19  38683.   7.17  3.02    3179.
      25           0.    76.83  34484.   7.06  2.02    3526.
      30           0.    67.62  30349.   6.93  1.07    3868.
      35           0.    58.76  26374.   6.75   .20    4202.
      40           0.    54.95  24665.   6.50   .00    4525.
      45           0.    52.41  23521.   6.20   .00    4834.
      50           0.    44.85  20131.   5.30   .00    5121.
      55           0.    13.91   6242.   1.64   .00    5246.
      57           0.      .00      0.    .00   .00    5248.
```

Figure 8
ORIFICE RUPTURE
CASE

```
                PRYOR-ATKINS JUNC M ALT
                ILLINOIS RIVER, OK
         26 JUN 80                                   CHAPMAN
         @09:07:16                                   79-11.2
                MATERIAL                             COAL
                SLURRY DENSITY                        1.142
                SAT VOL CONC                          .476
                SAT SOL DENSITY                       1.298
         PIPE INSIDE DIA(IN)                         39.376
         BREAKSIZE(IN)                                3.000
         FINAL HOLE SIZE(IN)                          3.831
         PIPELINE SECTION - MILEPOST          MB-410.50 to MB-485.50
         BREAKPOINT - MILEPOST                       MB-438.50

         MAX SPILL AFTER  935.0 MINS IS              66796.  BARRELS
         MAX SPILL AFTER  935.0 MINS IS               1329. TONS SAT COAL

    SPILL SUMMARY   LINE       FLOW          VELOCITY  MAX CUM SOLIDS
     (MINUTES)    PRESSURE  (CFS)  (GPM)       (FPS)   SPILLED(TONS)
                   (PSIG)                   (UPS) (DS)
          1         365.    10.50   4711.    .76   .48        2.
         60         234.     9.41   4225.    .00  1.11      198.
        120         193.     9.25   4153.    .84   .25      351.
        180         176.     9.40   4218.   1.08   .03      510.
        240         156.     9.35   4195.    .00  1.11      685.
        300         114.     8.29   3722.    .78   .20      788.
        360         105.     8.20   3678.    .77   .20      883.
        420          96.     8.08   3625.    .76   .20      974.
        480          87.     7.86   3528.    .74   .19     1063.
        540          73.     7.35   3300.    .35   .52     1139.
        600          50.     6.20   2784.    .30   .43     1188.
        660          34.     5.14   2305.    .61   .00     1239.
        720          22.     4.24   1902.    .00   .50     1280.
        780          13.     3.15   1416.    .00   .37     1307.
        840           6.     2.22    998.    .26   .00     1322.
        900           2.     1.17    527.    .14   .00     1328.
        935           0.      .00      0.    .00   .00     1329.
```

Figure 9
COMPLETE RUPTURE
CASE

```
              J.RANCH-OOLAGAH C ALT
              CEDAR BLUFF RES, KANSAS
       28 JUN 80                          CHAPMAN
       @11:29:31                          79-11.2
              MATERIAL                    COAL
              SLURRY DENSITY               1.142
              SAT VOL CONC                  .476
              SAT SOL DENSITY              1.298
       PIPE INSIDE DIA(IN)                45.118
       PIPELINE SECTION - MILEPOST    C-345.00 to C-519.00
       BREAKPOINT - MILEPOST             C-491.20

       MAX SPILL AFTER  965.0 MINS IS       544102.  BARRELS
       MAX SPILL AFTER  965.0 MINS IS        58438. TONS SAT COAL

SPILL SUMMARY    LINE       FLOW          VELOCITY  MAX CUM SOLIDS
 (MINUTES)     PRESSURE  (CFS)  (GPM)       (FPS)   SPILLED(TONS)
                (PSIG)                 (UPS) (DS)
        1          0.   291.92 131025.  9.36 16.93     338.
       60          0.    71.28  31994.  6.42   .00    6026.
      120          0.    71.28  31994.  6.42   .00   10973.
      180          0.    55.37  24854.  4.99   .00   15418.
      240          0.    52.88  23735.  4.76   .00   19175.
      300          0.    50.18  22524.  4.52   .00   22750.
      360          0.    49.38  22162.  4.45   .00   26189.
      420          0.    49.21  22088.  4.43   .00   29609.
      480          0.    49.06  22020.  4.42   .00   33019.
      540          0.    48.92  21958.  4.41   .00   36418.
      600          0.    48.79  21901.  4.39   .00   39808.
      660          0.    48.68  21849.  4.38   .00   43190.
      720          0.    48.57  21801.  4.37   .00   46564.
      780          0.    48.48  21759.  4.37   .00   49931.
      840          0.    48.39  21720.  4.36   .00   53292.
      900          0.    44.09  19787.  3.97   .00   56537.
      960          0.     7.81   3504.   .70   .00   58436.
      965          0.      .00      0.   .00   .00   58438.
```

```
          J.RANCH-OOLAGAH C ALT
          CEDAR BLUFF RES, KANSAS
     26 JUN 80                              CHAPMAN
     @09:35:02                              79-11.2
          MATERIAL                          COAL
          SLURRY DENSITY                     1.142
          SAT VOL CONC                       .476
          SAT SOL DENSITY                    1.298
     PIPE INSIDE DIA(IN)                    45.118
     BREAKSIZE(IN)                           3.000
     FINAL HOLE SIZE(IN)                     6.968
     PIPELINE SECTION - MILEPOST          C-345.00 to C-519.00
     BREAKPOINT - MILEPOST                   C-491.20

     MAX SPILL AFTER 1440.0 MINS IS          442935.  BARRELS
     MAX SPILL AFTER 1440.0 MINS IS           31958. TONS SAT COAL

 SPILL SUMMARY    LINE       FLOW          VELOCITY  MAX CUM SOLIDS
   (MINUTES)    PRESSURE  (CFS)  (GPM)       (FPS)   SPILLED(TONS)
                 (PSIG)                   (UPS) (DS)
        1         625.     3.97   1784.     .36  .00        0.
       60         550.    16.45   7382.    1.48  .00      340.
      120         514.    19.62   8805.    1.77  .00      852.
      180         476.    22.49  10096.    2.03  .00     1549.
      240         439.    25.02  11229.    2.25  .00     2436.
      300         401.    27.06  12147.    2.44  .00     3502.
      360         370.    28.91  12974.    2.60  .00     4725.
      420         342.    30.43  13658.    2.74  .00     6107.
      480         319.    31.88  14310.    2.87  .00     7623.
      540         289.    32.50  14586.    2.93  .00     9254.
      600         265.    33.09  14852.    2.98  .00    10945.
      660         244.    33.52  15045.    3.02  .00    12666.
      720         228.    34.00  15259.    3.06  .00    14449.
      780         214.    34.30  15396.    3.09  .00    16277.
      840         186.    33.19  14895.    2.99  .00    18058.
      900         164.    32.22  14461.    2.90  .00    19739.
      960         124.    28.75  12905.    2.59  .00    21198.
     1020         121.    28.96  13000.    2.61  .00    22497.
     1080         118.    29.12  13072.    2.62  .00    23815.
     1140         115.    29.33  13165.    2.64  .00    25150.
     1200         113.    29.48  13232.    2.66  .00    26501.
     1260         110.    29.59  13279.    2.66  .00    27865.
     1320         106.    29.59  13281.    2.66  .00    29233.
     1380         103.    29.48  13233.    2.66  .00    30598.
     1440          99.    29.49  13235.    2.66  .00    31958.
```

Figure 10
ORIFICE RUPTURE
CASE

Figure 11
COMPLETE RUPTURE
CASE

```
               W.BLUFF-AL.JUNC PROPOSED
               SALINE RIVER, ARKANSAS
          28 JUN 80                            CHAPMAN
          @11:34:56                            79-11.2
               MATERIAL                              COAL
               SLURRY DENSITY                   1.142
                 SAT VOL CONC                    .476
                 SAT SOL DENSITY                1.298
          PIPE INSIDE DIA(IN)                  31.446
          PIPELINE SECTION - MILEPOST    PM-1077.60 to PM-1137.60
          BREAKPOINT - MILEPOST                PM-1118.00

          MAX SPILL AFTER  401.0 MINS IS            25869.  BARRELS
          MAX SPILL AFTER  401.0 MINS IS             1123. TONS SAT COAL

     SPILL SUMMARY    LINE       FLOW           VELOCITY  MAX CUM SOLIDS
       (MINUTES)    PRESSURE  (CFS)  (GPM)        (FPS)   SPILLED(TONS)
                     (PSIG)                   (UPS) (DS)
             1         0.     30.96  13898.    5.74  .00       36.
            30         0.      9.11   4088.    1.69  .00      397.
            60         0.      8.81   3956.    1.63  .00      527.
            90         0.      8.41   3775.    1.56  .00      646.
           120         0.      7.96   3573.    1.48  .00      754.
           150         0.      7.45   3346.    1.38  .00      849.
           180         0.      6.87   3081.    1.27  .00      932.
           210         0.      6.15   2759.    1.14  .00     1000.
           240         0.      5.27   2364.     .98  .00     1052.
           270         0.      4.21   1890.     .78  .00     1088.
           300         0.      3.05   1371.     .57  .00     1110.
           330         0.      1.94    872.     .36  .00     1120.
           360         0.       .94    420.     .17  .00     1123.
           390         0.       .11     50.     .02  .00     1123.
           401         0.       .00      0.     .00  .00     1123.
```

Figure 12
ORIFICE RUPTURE
CASE

```
                W.BLUFF-AL.JUNC PROPOSED
                SALINE RIVER, ARKANSAS
      25 JUN 80                                  CHAPMAN
      @14:56:38                                  79-11.2
                MATERIAL                            COAL
                SLURRY DENSITY                    1.142
                SAT VOL CONC                       .476
                SAT SOL DENSITY                   1.298
      PIPE INSIDE DIA(IN)                        31.446
      BREAKSIZE(IN)                               3.000
      FINAL HOLE SIZE(IN)                         3.099
      PIPELINE SECTION - MILEPOST     PM-1077.60 to PM-1137.60
      BREAKPOINT - MILEPOST                      PM-1118.00

      MAX SPILL AFTER 1168.0 MINS IS              25735.  BARRELS
      MAX SPILL AFTER 1168.0 MINS IS                287. TONS SAT COAL

  SPILL SUMMARY    LINE        FLOW            VELOCITY  MAX CUM SOLIDS
   (MINUTES)     PRESSURE   (CFS)  (GPM)        (FPS)    SPILLED(TONS)
                  (PSIG)                     (UPS) (DS)
          1         29.      1.22    546.      .23   .00       0.
         60         24.      2.67   1199.      .50   .00      24.
        120         22.      2.63   1180.      .49   .00      46.
        180         22.      2.60   1169.      .48   .00      69.
        240         21.      2.59   1162.      .48   .00      90.
        300         21.      2.56   1149.      .47   .00     112.
        360         20.      2.51   1126.      .47   .00     132.
        420         18.      2.44   1096.      .45   .00     152.
        480         17.      2.36   1061.      .44   .00     170.
        540         15.      2.27   1020.      .42   .00     187.
        600         14.      2.17    974.      .40   .00     203.
        660         13.      2.06    923.      .38   .00     217.
        720         12.      2.01    902.      .37   .00     230.
        780         11.      1.87    840.      .35   .00     242.
        840          9.      1.82    816.      .34   .00     253.
        900          8.      1.66    744.      .31   .00     263.
        960          7.      1.60    716.      .30   .00     272.
       1020          6.      1.36    612.      .25   .00     279.
       1080          3.       .98    440.      .18   .00     284.
       1140          1.       .63    282.      .12   .00     286.
       1168          0.       .00      0.      .00   .00     287.
```

Figure 13
COMPLETE RUPTURE
CASE

```
                 AL.JUNC-L.CHAR PROPOSED
                 BAYOU COCODRIE, LA
          28 JUN 80                                  CHAPMAN
          @11:42:12                                  79-11.2
                 MATERIAL                            COAL
                 SLURRY DENSITY                       1.142
                 SAT VOL CONC                          .476
                 SAT SOL DENSITY                      1.298
          PIPE INSIDE DIA(IN)                        13.500
          PIPELINE SECTION - MILEPOST     PM-1315.00 to PM-1360.00
          BREAKPOINT - MILEPOST                  PM-1338.00

          MAX SPILL AFTER  185.0 MINS IS              3875.  BARRELS
          MAX SPILL AFTER  185.0 MINS IS               227. TONS SAT COAL

     SPILL SUMMARY    LINE       FLOW          VELOCITY  MAX CUM SOLIDS
      (MINUTES)     PRESSURE  (CFS)  (GPM)       (FPS)   SPILLED(TONS)
                     (PSIG)                  (UPS)  (DS)
          1            0.      5.15  2313.   2.89  2.29        4.
         15            0.      5.00  2243.   2.74  2.29       57.
         30            0.      4.78  2148.   2.52  2.29      109.
         45            0.      4.51  2022.   2.24  2.29      156.
         60            0.      4.15  1861.   1.88  2.29      197.
         75            0.      1.43   642.   1.44   .00      218.
         90            0.       .95   426.    .95   .00      224.
        105            0.       .52   234.    .52   .00      227.
        120            0.       .27   120.    .27   .00      227.
        135            0.       .16    74.    .17   .00      227.
        150            0.       .10    46.    .10   .00      227.
        165            0.       .05    22.    .05   .00      227.
        180            0.       .01     3.    .01   .00      227.
        185            0.       .00     0.    .00   .00      227.
```

Figure 14
ORIFICE RUPTURE

```
                AL.JUNC-L.CHAR PROPOSED
                BAYOU COCODRIE, LA
        25 JUN 80                            CHAPMAN
        @14:54:40                            79-11.2
                MATERIAL                     COAL
                SLURRY DENSITY                1.142
                SAT VOL CONC                   .476
                SAT SOL DENSITY               1.298
        PIPE INSIDE DIA(IN)                  13.500
        BREAKSIZE(IN)                         3.000
        FINAL HOLE SIZE(IN)                   3.008
        PIPELINE SECTION - MILEPOST     PM-1315.00 to PM-1360.00
        BREAKPOINT - MILEPOST                PM-1338.00

        MAX SPILL AFTER  300.0 MINS IS              3740.  BARRELS
        MAX SPILL AFTER  300.0 MINS IS                99. TONS SAT COAL

  SPILL SUMMARY    LINE       FLOW            VELOCITY  MAX CUM SOLIDS
    (MINUTES)    PRESSURE  (CFS)  (GPM)         (FPS)   SPILLED(TONS)
                  (PSIG)                     (UPS) (DS)
        1          16.     1.49    667.     1.50   .00         1.
       60           9.     1.60    717.     1.39   .22        51.
      120           6.     1.40    626.      .69   .72        74.
      180           4.     1.03    464.      .27   .77        87.
      240           2.      .71    320.      .18   .54        96.
      300           0.      .00      0.      .00   .00        99.
```

```
                  AL.JUNC-N.ROADS PRu/OSED
                  BTMLND-HRDWDS AREA, LA
          28 JUN 80                              CHAPMAN
          @11:45:26                              79-11.2
                  MATERIAL                         COAL
                  SLURRY DENSITY                  1.142
                  SAT VOL CONC                     .476
                  SAT SOL DENSITY                 1.298
          PIPE INSIDE DIA(IN)                    25.500
          PIPELINE SECTION - MILEPOST   PM(NW)-0.00 to PM(NW)-75.60
          BREAKPOINT - MILEPOST                  PM(NW)-48.00

          MAX SPILL AFTER 1440.0 MINS IS           50897.  BARRELS
          MAX SPILL AFTER 1440.0 MINS IS            1443. TONS SAT COAL

   SPILL SUMMARY    LINE      FLOW          VELOCITY  MAX CUM SOLIDS
     (MINUTES)    PRESSURE  (CFS)  (GPM)      (FPS)   SPILLED(TONS)
                   (PSIG)                  (UPS) (DS)
           1          0.     9.83  4414.   1.65  1.12        4.
          60          0.     5.60  2513.   1.58   .00      174.
         120          0.     5.40  2423.   1.52   .00      321.
         180          0.     5.18  2324.   1.46   .00      458.
         240          0.     4.93  2213.   1.39   .00      583.
         300          0.     4.66  2089.   1.31   .00      695.
         360          0.     4.35  1954.   1.23   .00      795.
         420          0.     4.03  1809.   1.14   .00      881.
         480          0.     3.70  1661.   1.04   .00      954.
         540          0.     3.38  1517.    .95   .00     1015.
         600          0.     3.09  1387.    .87   .00     1066.
         660          0.     2.84  1276.    .80   .00     1109.
         720          0.     2.65  1188.    .75   .00     1145.
         780          0.     2.50  1122.    .70   .00     1178.
         840          0.     2.39  1074.    .67   .00     1207.
         900          0.     2.32  1039.    .65   .00     1234.
         960          0.     2.26  1015.    .64   .00     1260.
        1020          0.     2.22   998.    .63   .00     1284.
        1080          0.     2.19   985.    .62   .00     1308.
        1140          0.     2.17   975.    .61   .00     1331.
        1200          0.     2.16   967.    .61   .00     1354.
        1260          0.     2.14   961.    .60   .00     1377.
        1320          0.     2.13   956.    .60   .00     1399.
        1380          0.     2.12   951.    .60   .00     1421.
        1440          0.     2.11   947.    .60   .00     1443.
```

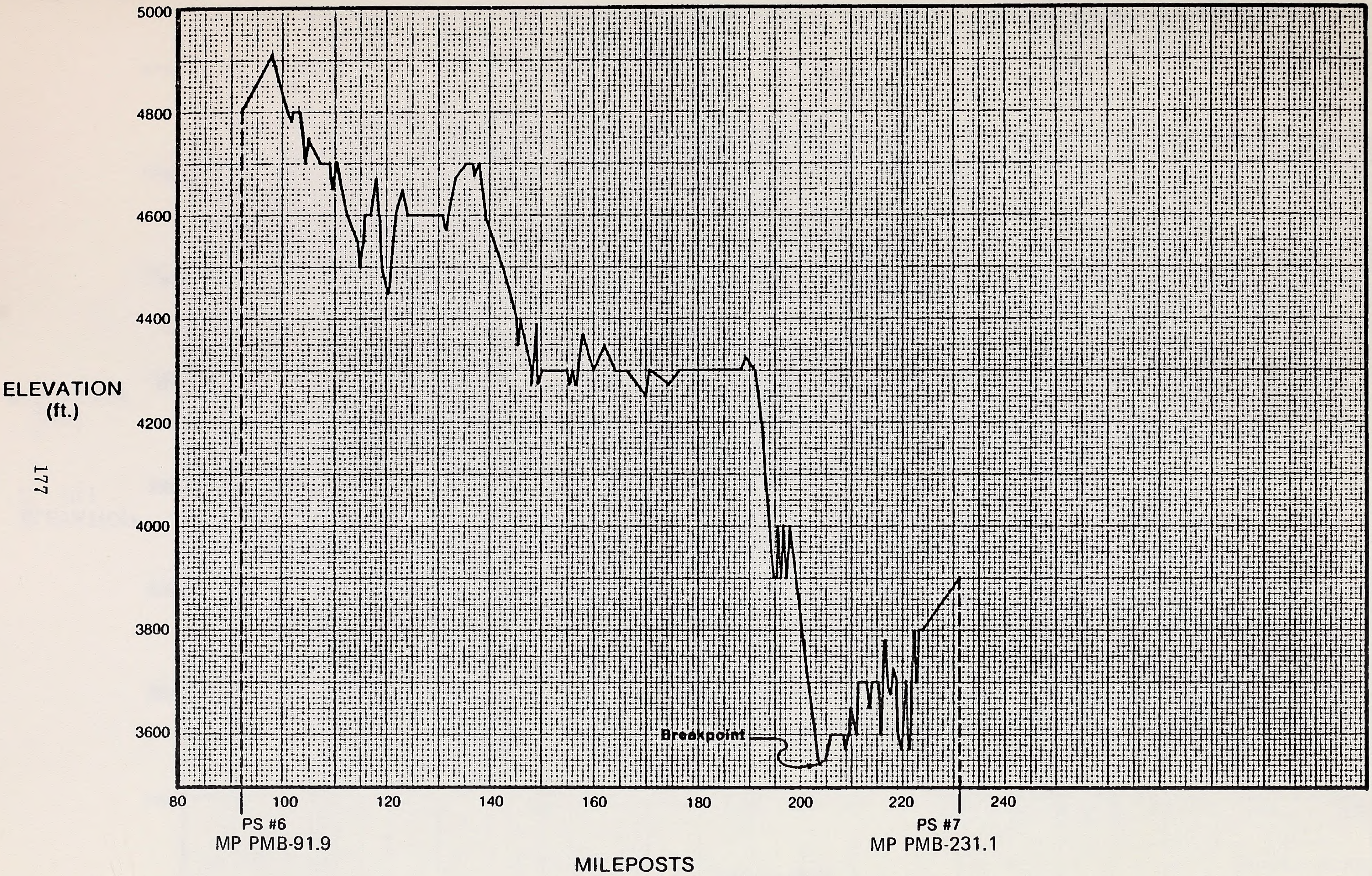
Figure 15
COMPLETE RUPTURE
CASE

```
                AL.JUNC-N.ROADS PROPOSED
                BTMLND-HRDWDS AREA, LA
           25 JUN 80                             CHAPMAN
           @14:50:44                             79-11.2
                MATERIAL                           COAL
                SLURRY DENSITY                    1.142
                SAT VOL CONC                       .476
                SAT SOL DENSITY                   1.298
           PIPE INSIDE DIA(IN)                   25.500
           BREAKSIZE(IN)                          3.000
           FINAL HOLE SIZE(IN)                    3.104
           PIPELINE SECTION - MILEPOST   PM(NW)-0.00 to PM(NW)-75.60
           BREAKPOINT - MILEPOST                PM(NW)-48.00

           MAX SPILL AFTER 1440.0 MINS IS           31152.  BARRELS
           MAX SPILL AFTER 1440.0 MINS IS             481.  TONS SAT COAL

     SPILL SUMMARY    LINE        FLOW            VELOCITY  MAX CUM SOLIDS
      (MINUTES)     PRESSURE  (CFS)  (GPM)          (FPS)   SPILLED(TONS)
                     (PSIG)                      (UPS) (DS)
            1         20.      1.36   611.        .38   .00        0.
           60         14.      2.10   942.        .59   .00       21.
          120         14.      2.09   939.        .59   .00       42.
          180         14.      2.04   915.        .58   .00       63.
          240         14.      2.03   913.        .57   .00       84.
          300         13.      2.03   909.        .57   .00      104.
          360         13.      1.98   890.        .56   .00      124.
          420         13.      1.97   885.        .56   .00      143.
          480         13.      1.97   885.        .56   .00      162.
          540         13.      2.00   898.        .56   .00      181.
          600         13.      2.00   897.        .56   .00      201.
          660         12.      2.03   910.        .57   .00      221.
          720         12.      2.03   910.        .57   .00      241.
          780         12.      2.03   909.        .57   .00      261.
          840         12.      2.02   909.        .57   .00      281.
          900         12.      2.02   908.        .57   .00      301.
          960         12.      2.02   907.        .57   .00      321.
         1020         12.      2.02   907.        .57   .00      341.
         1080         12.      2.02   906.        .57   .00      361.
         1140         12.      2.02   905.        .57   .00      381.
         1200         12.      2.02   905.        .57   .00      401.
         1260         12.      2.01   904.        .57   .00      420.
         1320         12.      2.05   919.        .58   .00      440.
         1380         12.      2.05   918.        .58   .00      461.
         1440         12.      2.04   918.        .58   .00      481.
```

Figure 16
ORIFICE RUPTURE
CASE

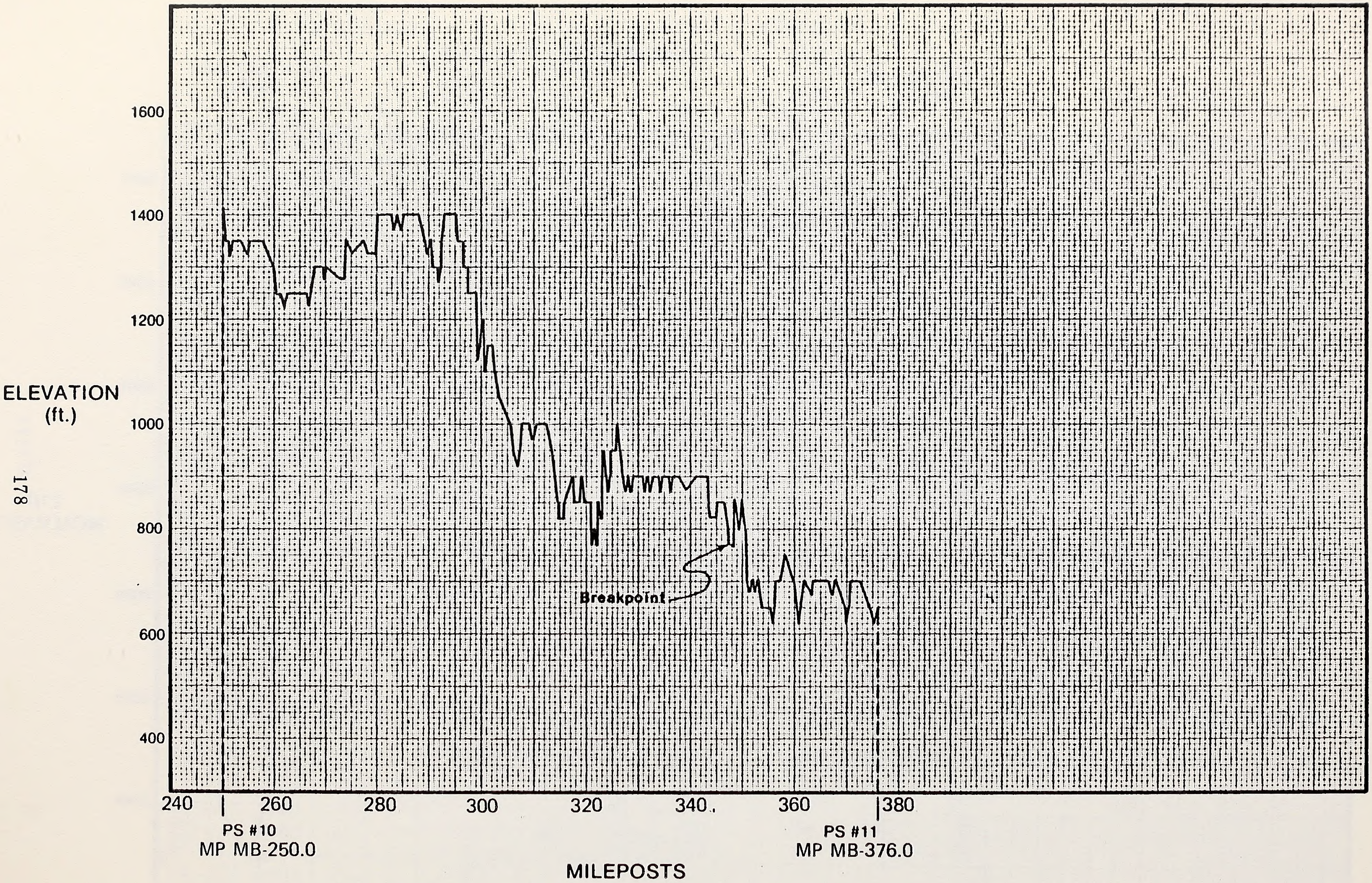


PSI

Figure 17

NORTH PLATTE RIVER, NEBRASKA

JR-PCP

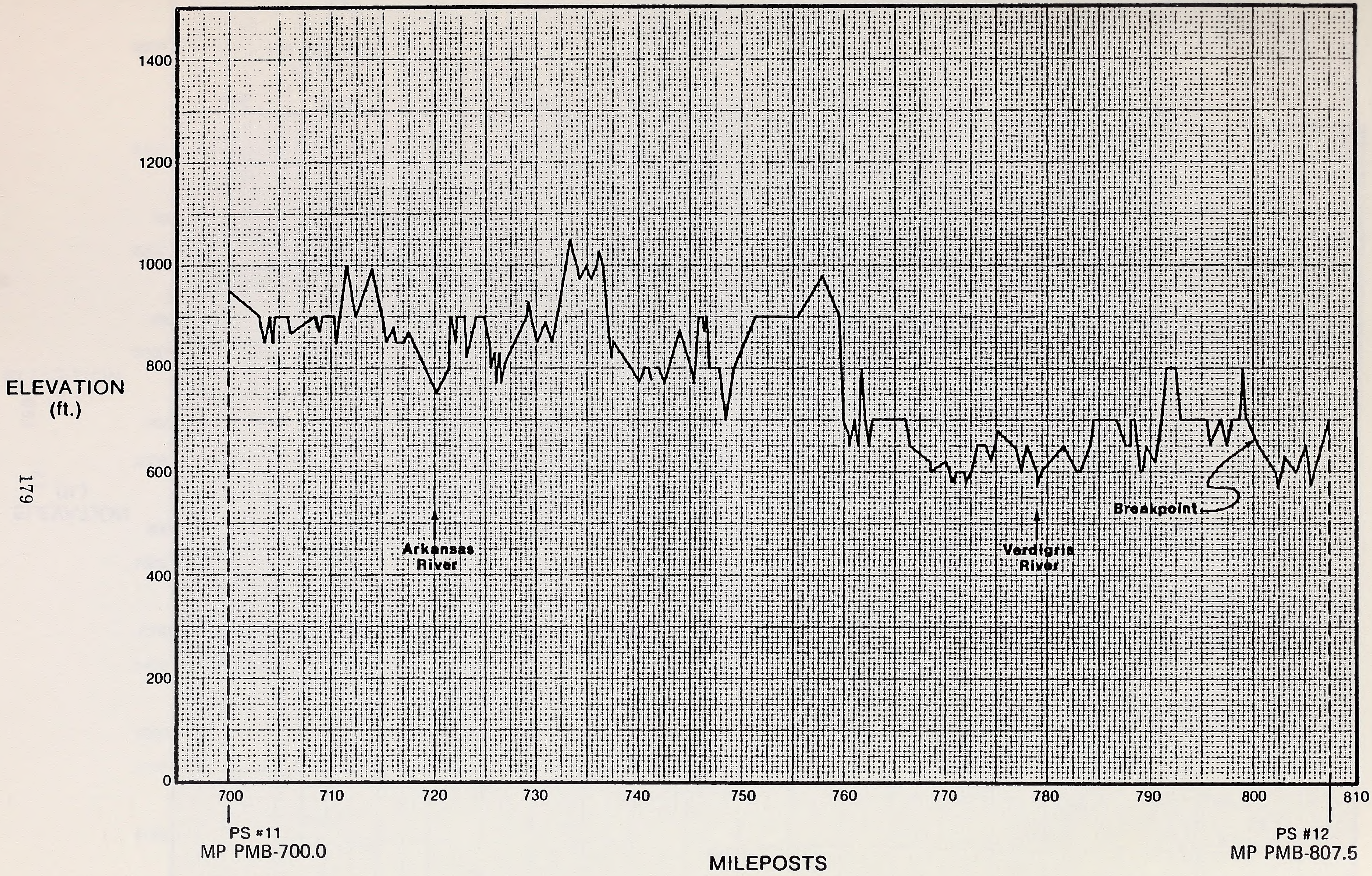


PSI

Figure 18
SAND CREEK, OKLAHOMA

Rev 1

JR-00L

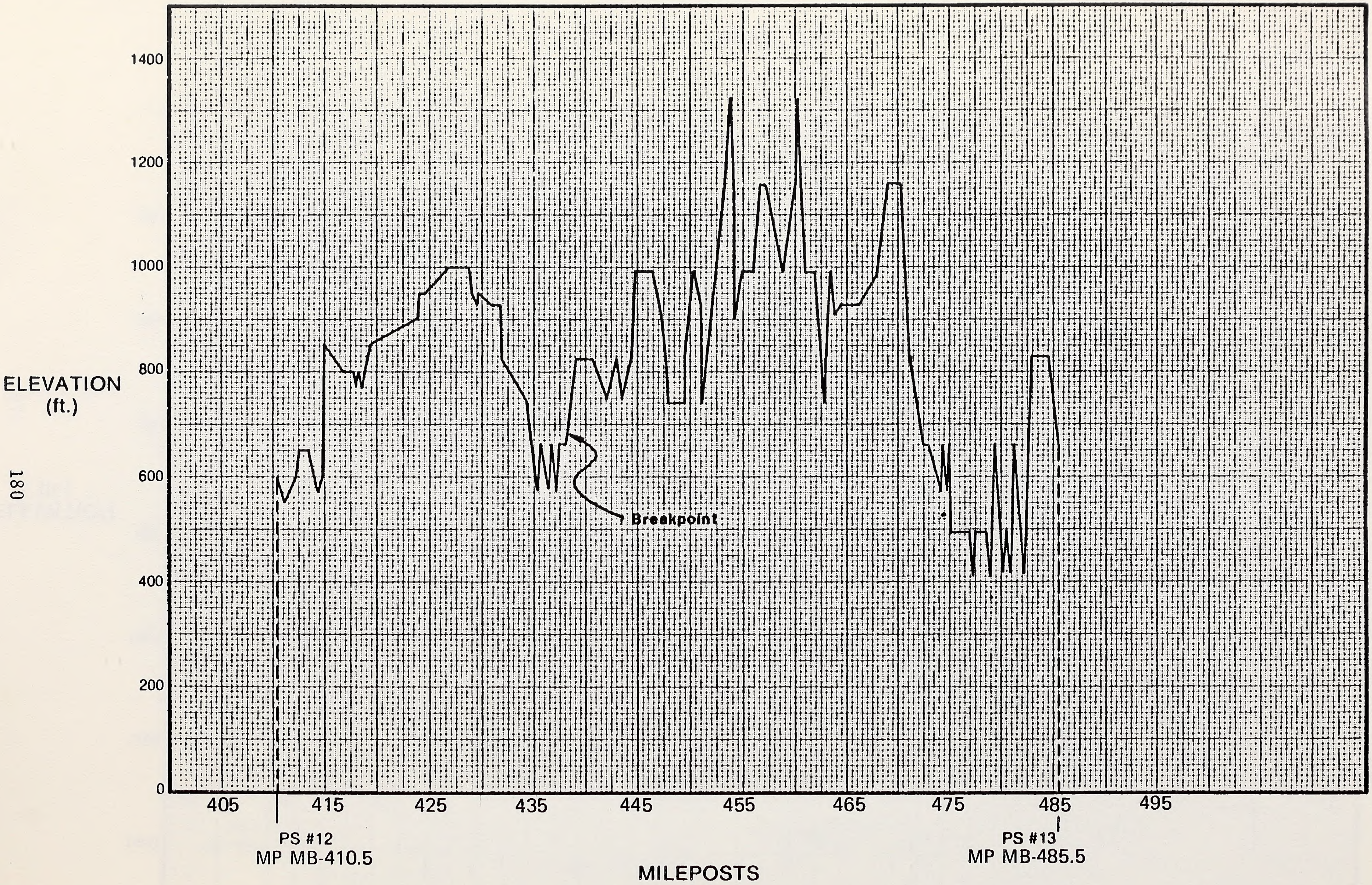


PSI

Figure 19

RECREATIONAL AREA, OKLAHOMA

PC-PR



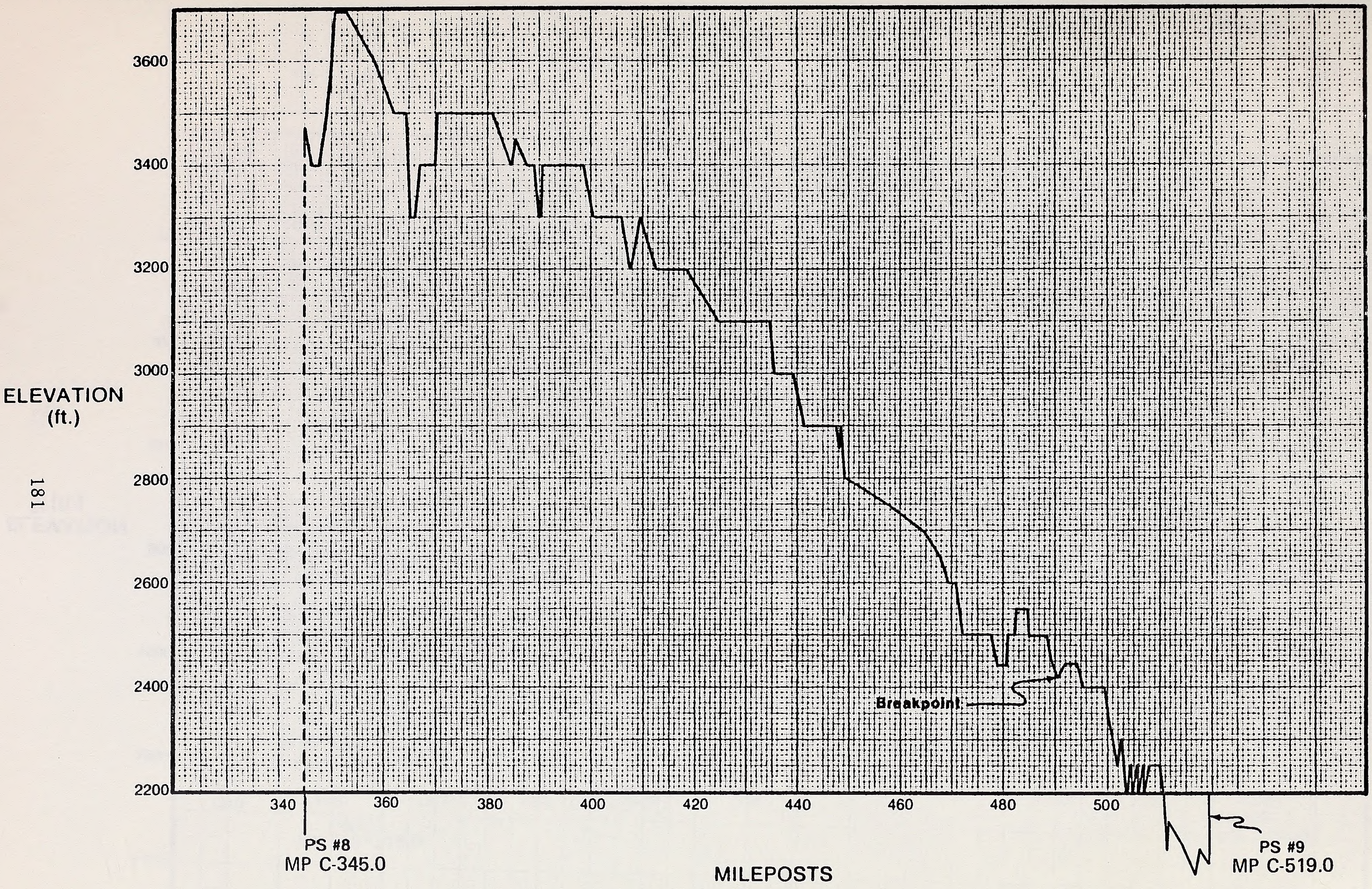
PSI

Figure 20

ILLINOIS RIVER, OKLAHOMA

Rev. 1

PR-ATK

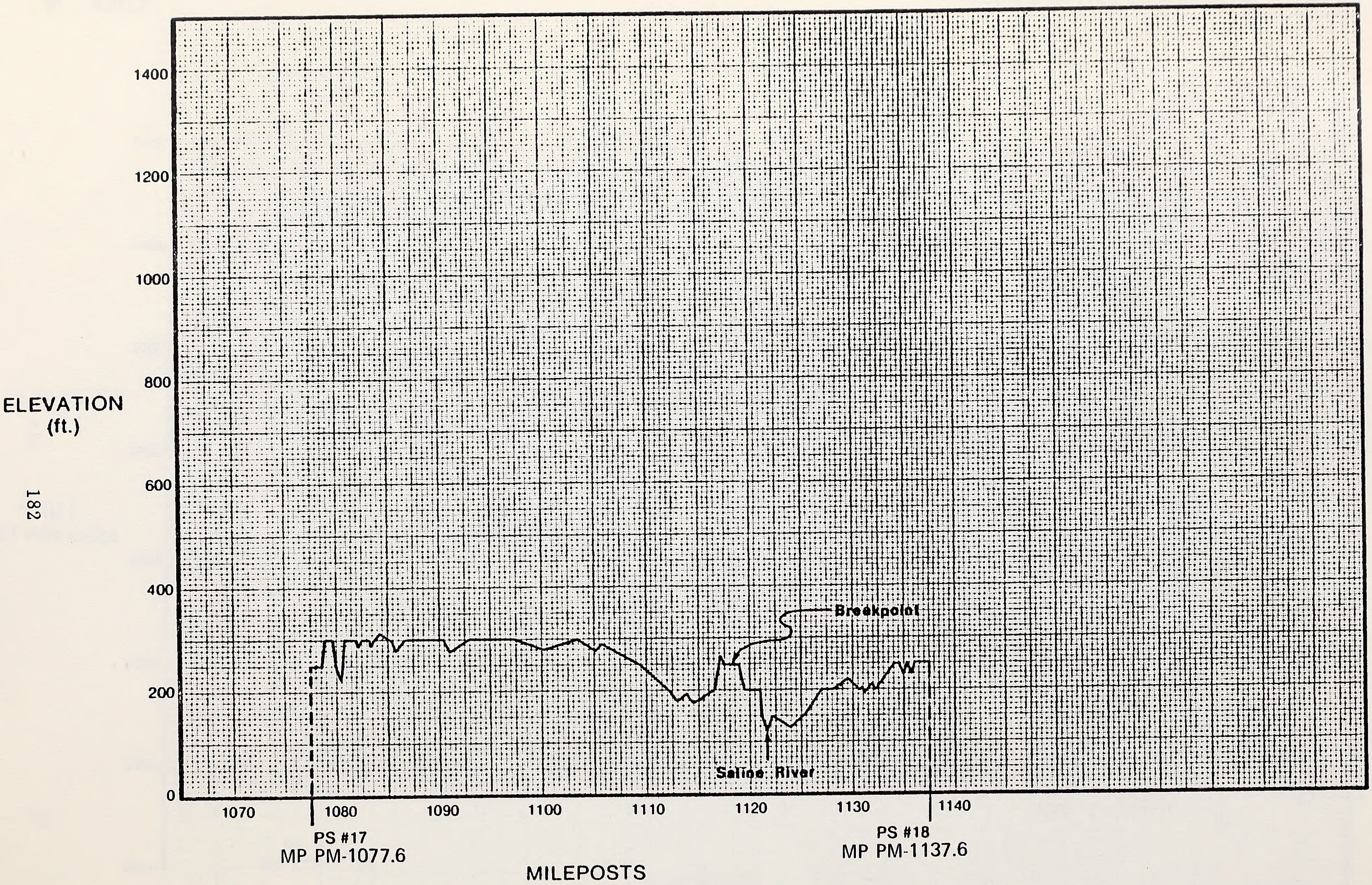


PSI

Figure 21

CEDAR BLUFF RESERVOIR, KANSAS

JR-00L



PSI

Figure 22

SALINE RIVER, ARKANSAS

WB-AL

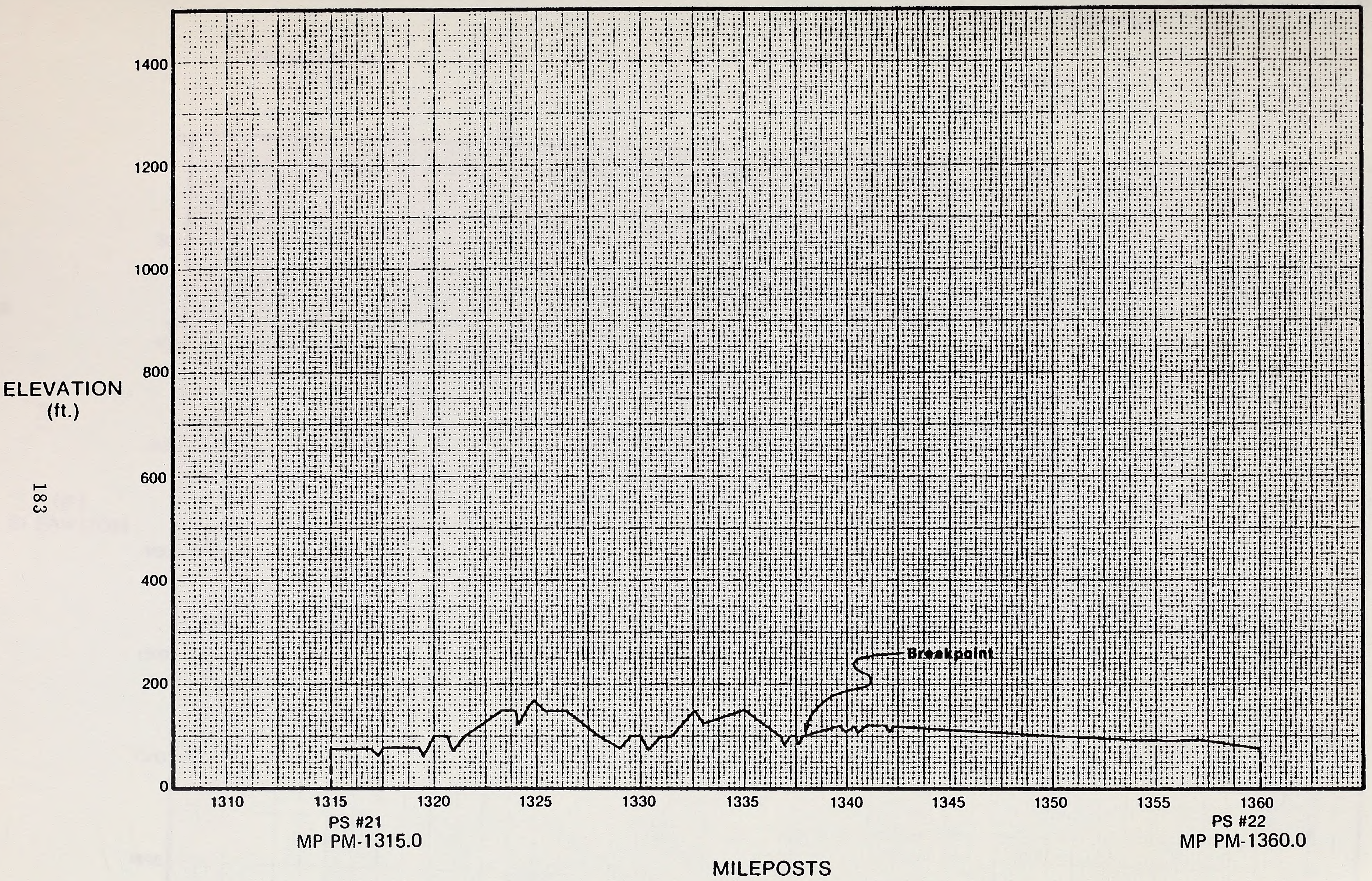


Figure 23

BAYOU COCODRIE, LOUISIANA

AL-LC

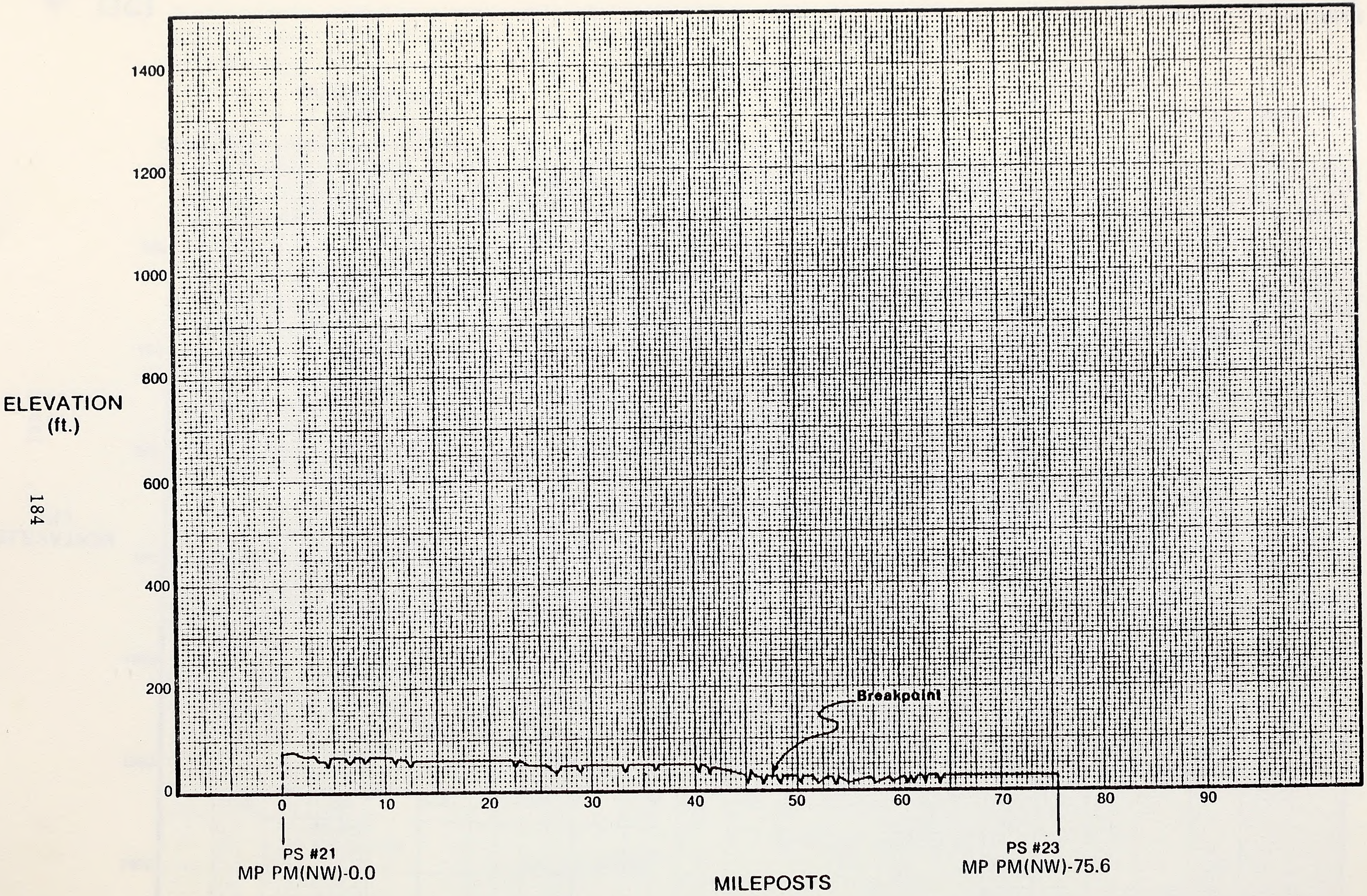


Figure 24

BOTTOMLAND - HARDWOODS AREA, LOUISIANA

PSI

AL-NWR

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